Section 3

ENVIRONMENTAL SETTING

ENVIRONMENTAL SETTING

Section 3 contains information about the environmental setting of the Navajo Nation. Maps and associated text and tables are presented that describe administrative boundaries and infrastructure features, climate, topography, physiography and geology, hydrology, soils, and land cover. All of the datasets were prepared using existing data sources, and no field verifications were conducted as part of this project.

The Navajo Nation (Dine'é) is the largest Indian reservation in the United States, covering an area of about 27,000 square miles. The Navajo Nation is comprised of 110 Chapters, including three (3) Navajo satellite reservations: Alamo, Ramah, and Tohajiilee. This area includes a large part of northeastern Arizona, northwestern New Mexico and a small part of southeastern Utah, and is contained within eleven (11) counties (Figure 1). Hopi Reservation tribal lands are located within the Navajo Nation boundaries. On November 4, 2006 the Navajo-Hopi Intergovernmental Compact was signed to lift the 40-year old Bennett Freeze restriction on development, making the area around Moenkopi part of the Hopi Reservation. The eastern portion of the Navajo reservation, located in New Mexico, is commonly referred to as the "Checkerboard" because tribal trust lands are mingled with fee lands (owned by both Navajo and non-Navajo) and federal and state lands under various jurisdictions. The Navajo Nation is generally sparsely populated. The 2000 Census reported a population of 180,462 on the Navajo Nation Reservation and off-reservation trust land.

The Navajo Nation is predominantly located in the Colorado Plateau physiographic province. There is significant topographic relief across the nation, including broad mesas, canyons, dry washes, and mountains. Elevations range from a low of 3,080 feet at the gauging station across from Lee’s Ferry in Marble Canyon to over 10,346 feet at Navajo Mountain. Generally elevations across the Navajo Nation range from about 5,000 feet in the broad valleys to over 8,500 feet in the mountains.

The Colorado Plateau covers 130,000 square miles across northern Arizona, southwestern Utah, western Colorado, and northwestern New Mexico. The Navajo Nation is in the southern half of the Plateau, known as the Navajo Section. The landforms in the region are characterized and affected by alternating resistant and weak rock strata. Flat lying sedimentary rocks occur in an alternating sequence of resistant sandstones and limestones and less resistant shales and siltstones. Resistant beds form ledges, cliffs, mesas, and rock benches that are separated by slopes and valleys carved in the weaker beds. The Plateau was broadly and gently uplifted 10 million years ago generally placing the Navajo Nation over a mile high.

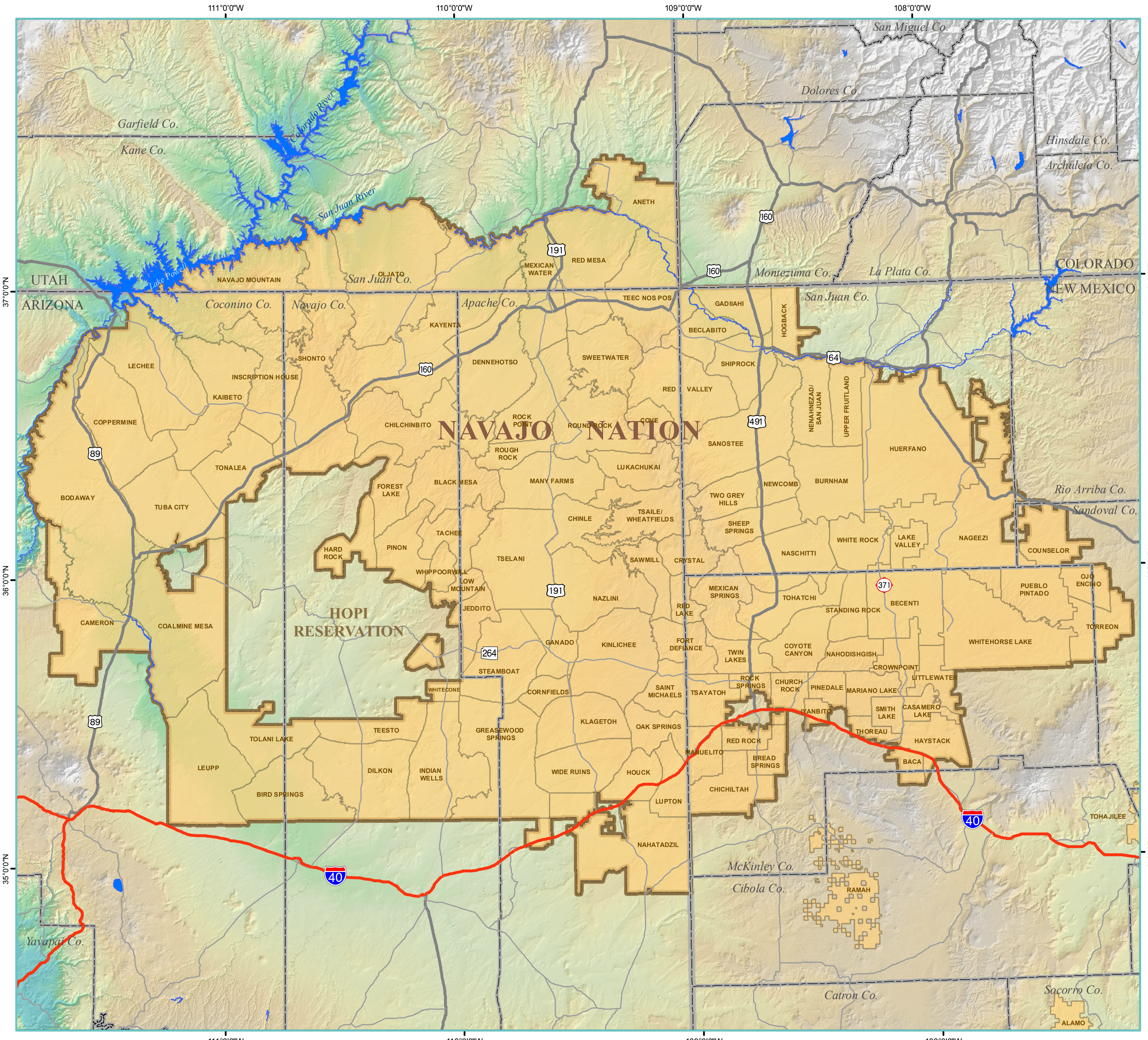
The perennial river valleys on the Navajo Nation include the Puerco, the Little Colorado, the Colorado, and the San Juan. All the other streams are intermittent or ephemeral, except for short reaches downstream from large springs and where the streambed intersects a water table. The underlying bedrock aquifers are composed of beds of sandstone between nearly impermeable layers of siltstone and mudstone. There are also near-surface alluvial aquifers.

The climate of the Navajo Nation varies widely, ranging from semiarid below 4,500 feet to relatively humid above 7,500 feet. Precipitation has a strong and fairly uniform relationship to altitude and the orographic effects of the physiography. The largely semiarid Navajo Nation is shown by the dominance of the 4-12 inch precipitation range. This low precipitation is due to the rain shadow effect of the Sierra Nevada Mountains of California in winter and quasi-permanent subtropical high pressure ridge over the region (Sheppard and others, 1999 - S0728303). Thunderstorms during the summer months account for most of the annual rainfall.

Minimum and maximum annual average temperatures are also directly related to the orographic effect. The higher elevations of the Chuska and Carrizo Mountains, the Defiance Plateau and Black Mesa have summer maximum high temperatures of 66º F or less. The remainder of the Navajo Nation averages more than 66º F. In the lower elevations within the Marble and Little Colorado Canyons, temperatures can average as high as 80º F in the summer. In the winter these same topographically higher areas average below freezing, whereas most of the remainder of the Navajo Nation is above freezing, but in the 30’s. The valleys of the Little Colorado, Colorado, Lake Powell, and the San Juan River up to about Comb Ridge in Utah average about 40º F in the winter (Sheppard and others, 1999 - S0728303).

Except for the months of August and September, strong south winds, with abundant dust and sand, blow almost constantly (Harshbarger, 1946 - S04170306). The prevailing wind direction is from the southwest throughout the region, which is widely displayed in dunes and eroded surfaces (Cooley et al, 1969 - S10290201).

Elevation largely determines what type of biotic communities will exist in a given location, as temperatures generally decrease and precipitation increases as one moves upward (Grahame, 2002 - S06020701). Vegetation in the area ranges from sparse desert scrub/ grassland in the valley to piñon-juniper woodlands at elevations from about 5,000 to 7,000 feet, with coniferous forests at elevations above 7,000 feet. Annual precipitation is typically from 10 to about 15 inches in piñon-juniper woodlands, and tree species in these communities have evolved both drought and cold resistance. Piñons dominate at higher elevations and juniper tends to grow at lower elevations and in more arid areas. Much of the Navajo Nation is sparsely vegetated with sagebrush, tamarisk, and other desert vegetation which is used by local residents for livestock grazing. Small-scale farming of row crops, such as corn and squash, is practiced. In open areas, residents are typically allotted one-acre home site leases. Grazing permits given to residents that own animals can range from 10 to 100 acres.



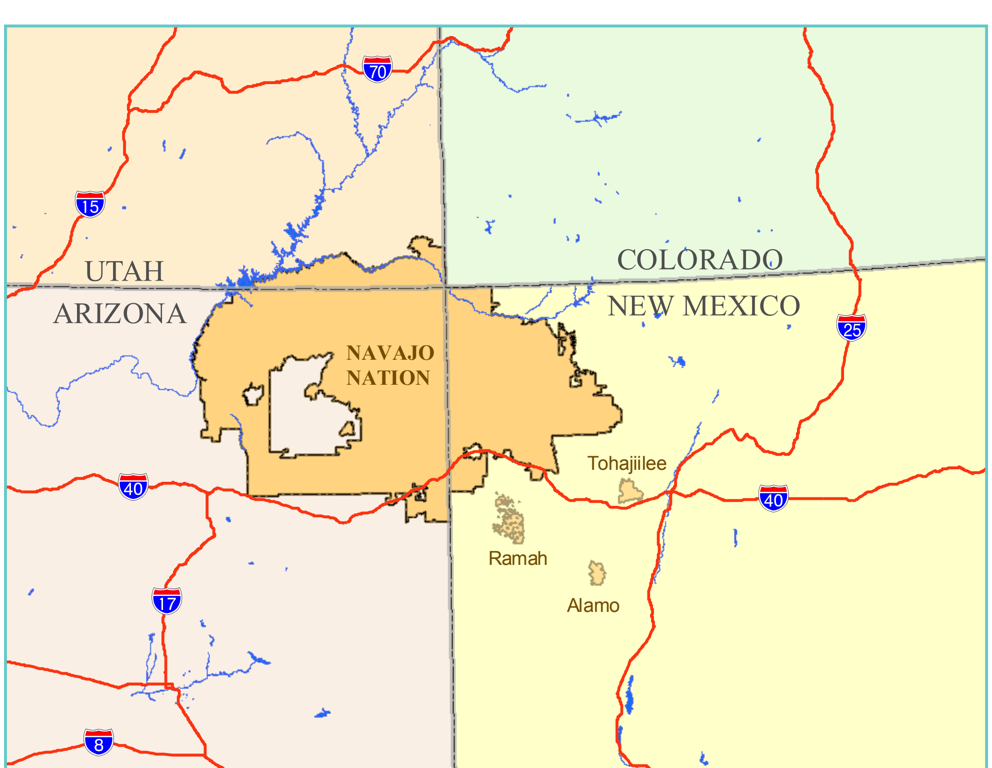
ABANDONED URANIUM MINES AND THE NAVAJO NATION

NAVAJO NATION

N
W E
S

0 50 Miles

Map Scale 1:1,750,000



Legend

Navajo Nation Chapter

State

County

Sources

The Navajo Nation Chapter boundaries are from the Navajo Land Department.
Filename: DB/Boundary/Navajo_Nation.shp

The state boundaries are from the National Transportation Atlas Databases (NTAD) 2002. The dataset has been clipped to the "four corner" states: Arizona, Colorado, New Mexico, and Utah.
Filename: DB/Boundary/NN_State.shp

The county boundaries are from the National Transportation Atlas Databases (NTAD) 2002. The dataset has been clipped to the "four corner" states: Arizona, Colorado, New Mexico, and Utah.
Filename: DB/Boundary/NN_County.shp

Figure 1. Location of the Navajo Nation.

LAND STATUS

The original Navajo Reservation was established by the Treaty of 1868 between the United States of America and the Navajo Tribe of Indians. A reservation of 3,539,500 acres, divided almost equally between Arizona and New Mexico, was defined by the treaty. The Checkerboard area was not part of this original treaty. Additions of lands to the reservation have been made by a series of Executive Orders and Acts of Congress (Cabeen, 1958 - S09210601). During the next 138 years, numerous Executive Orders and Public Land Orders exchanged, bought, assigned and reassigned the land base while additional areas were homesteaded. Figure 2 provides a map with the years of enactments between 1868 and 1934 that led to the creation of the Navajo Nation (Winson, 2002 - S11160601).

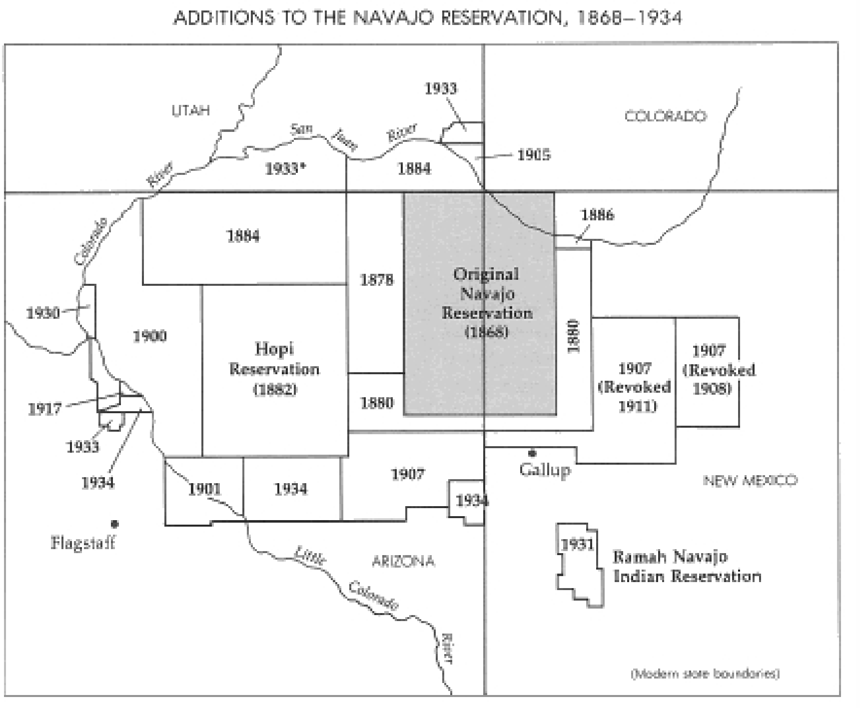


Figure 2. Additions to the Navajo Reservation, 1868 - 1934.

Most of the Navajo Nation consists of Tribal Trust Lands, or areas that are federally recognized and controlled by the tribe. However, as a result of the General Allotment Act of 1887 (commonly referred to as the Dawes Act) that allotted a specified amount of land to each Indian, lands within reservation boundaries may have a variety of types of ownership: tribal, individual Indian, non-Indian, as well as a mix of trust and fee lands (Figure 3). The eastern portion of the Navajo Nation, located in northwestern New Mexico, is such an area, and is referred to as the "Checkerboard area." Within the Checkerboard area there are several land ownership categories, including tribal trust lands, Indian allotments, Navajo tribal fee lands, federal and state lands:

"Tribal Trust Lands" are land where the title is held in trust by the United States for an individual Indian or a tribe.

"Indian Allotments" refer to land owned by individual Indians and is either held in trust by the United States or subject to statutory restriction on alienation. Most allotments were originally carved out of tribal lands held in common.

"Navajo Tribal Fee Land" are alienable by the tribe and taxable by the county.

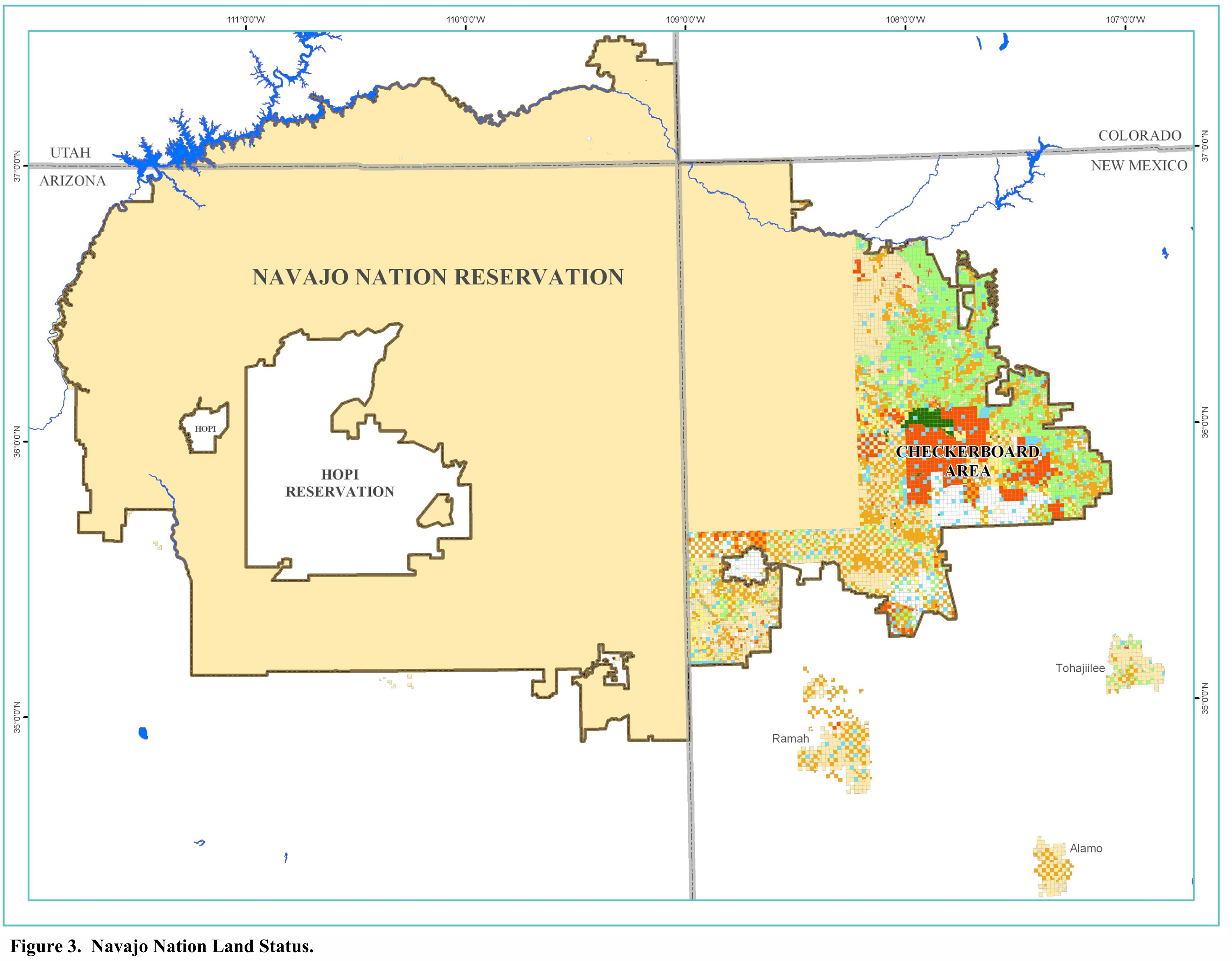
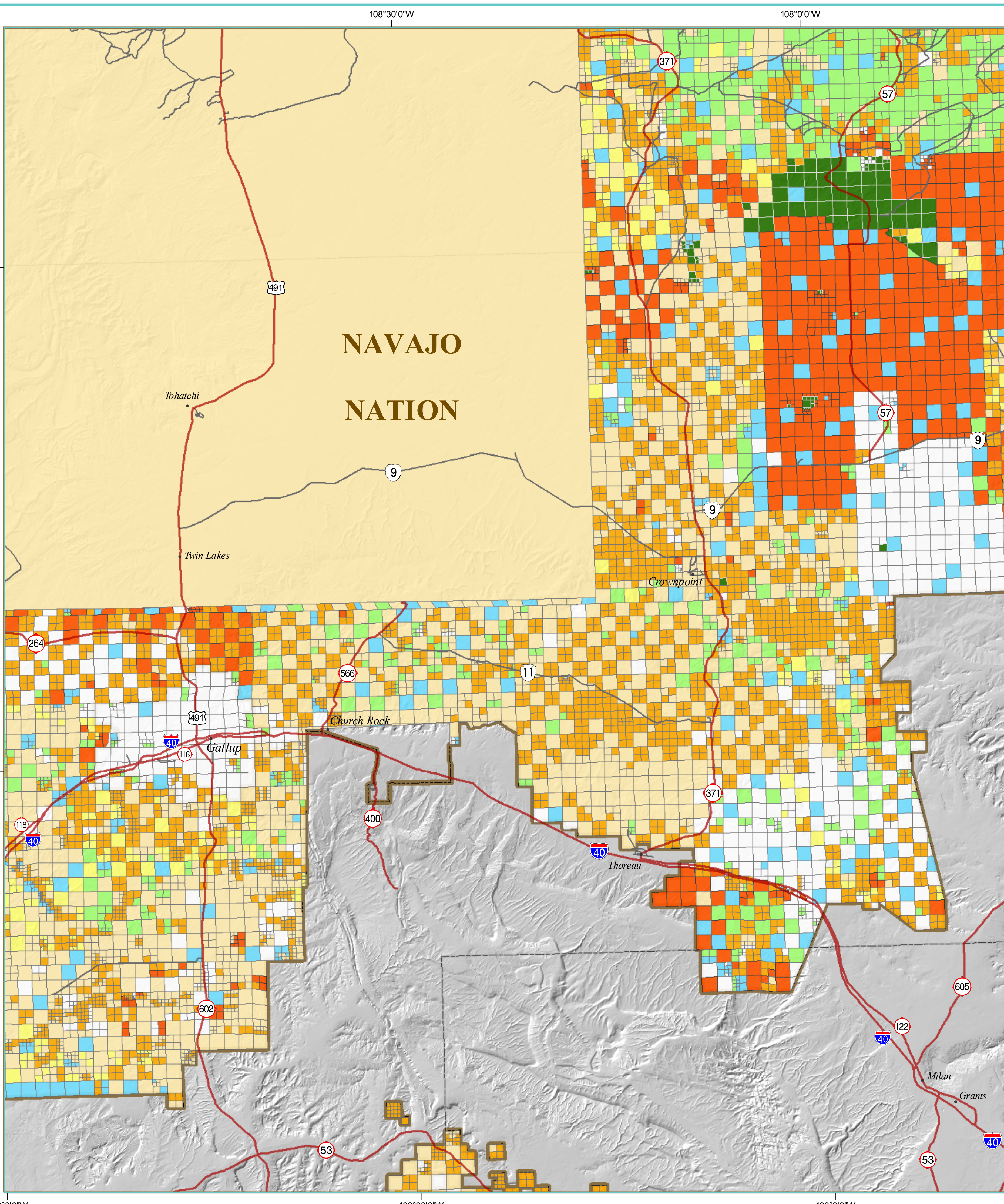


Figure 3. Navajo Nation Land Status.

Figure 4 shows land ownership for the Checkerboard area of the Navajo Nation. This dataset depicts the surface owner or manager of the land parcels. BLM's Master Title Plats are the official land records of the federal government and serve as the primary data source for all federal lands. Information from the State of New Mexico is the primary source for all state lands. The Navajo Land Department (NLD) GIS Section further processed the land ownership dataset and attributed the Indian Lands polygons into Navajo Tribal Trust, Indian Allotment, Navajo Tribal Fee, and Public Land Order numbers. The NLD oversees Navajo Nation land development projects and coordinates projects with the Navajo Nation, Bureau of Indian Affairs, Bureau of Land Management, State, County, private, and other entities involved. This dataset is provided on the GIS Data DVD (DB/Boundary/NN_Land_Status.shp).



ABANDONED URANIUM MINES AND THE NAVAJO NATION

LAND STATUS

0 5 10 Miles

Map Scale 1:450,000

Sources

These data were collected by the U.S. Bureau of Land Management (BLM) in New Mexico at both the New Mexico State Office and at the various field offices. The Navajo Land Department further processed and attributed the Indian Lands polygons into Navajo Tribal Trust, Indian Allotment, Navajo Tribal Fee, and Public Land Order (PLO) by PLO Number.

Filename: DB/Boundary/NN_Land_Status.shp

Legend

NAVAJO NATION SURFACE LAND STATUS

- Navajo Tribal Trust
- Navajo Tribal Fee
- Indian Allotment
- Public Land Order Land
- Bureau of Land Management
- National Park Service
- State
- Private

Figure 4. Land Status in the Eastern Navajo Nation.

NAVAJO NATION ADMINISTRATIVE BOUNDARIES

The Navajo Reservation was established with the Treaty of 1868. Congress ended treaty-making with Indian tribes in 1871 (Bureau of Indian Affairs, 2001 - S05050301). Since then, several Executive Orders and administrative acts have added lands to the original boundaries of the Treaty of 1868 (see Figure 2, page 3-4). The Navajo Reservation is the largest Indian reservation in the United States, and stretches across northwest New Mexico, northeast Arizona, and southeast Utah.

Three Navajo satellite communities are located in New Mexico. These are the Alamo Band of Navajo, located about 30 miles west of Magdalena, the Canoncito Band of Navajo, located in the Tohajiilee Chapter about 25 miles west of Albuquerque, and the Ramah Band of Navajo, which is located about 40 miles south of Gallup. The Navajo Nation also owns four (4) ranches that are outside the boundaries of the Navajo Nation: Big Boquillas Ranch, Crow Mesa Ranch, Espil Ranch, and the Largo Ranch. Neither these satellite communities nor the ranches have been included in the abandoned uranium mine screening assessments.

The sovereign relationship between the governments of the Navajo Nation and the United States was established in the Treaty of 1868. The Navajo Nation is recognized by the United States as a distinct, independent, political community able to exercise powers of self-government (Bayless, 2000 - S05050303). The capital of the Navajo Nation is located in Window Rock, Arizona. The Navajo Nation conducts a government-to-government relationship with the U.S. Government wherein no decisions about their lands and people are made without their consent (BIA, 2001 - S05050301). In 1921, oil was discovered in northwest New Mexico and the first form of the Navajo Tribal Council, a six-member business council, was created for the sole purpose of giving consent to mineral leases. The Navajo Nation did not adopt the Indian Reorganization Act of 1934 and does not operate under a constitution (SW Strategy, 2003 - S05050302). In 1936, the "Rules of the Navajo Tribal Council," were issued, which formed the basis for the Navajo Nation's government. The Navajo Nation Code sets forth the laws of the Navajo Nation.

The Navajo Nation government is a representative form of government with a President, Vice-President, and Council Delegates elected by the Navajo people. It acts by resolution and is separated into three branches: Executive, Legislative, and Judicial. The 88 members of the Council are elected, based on the population of the 110 chapters. The Council is the governing body of the Navajo Nation and its meetings are presided over by the Speaker who is elected by the membership of the Council. The Navajo Nation Council meets four times a year to enact legislation and discuss other issues of importance to the Navajo people. The Executive Branch is headed by a President and Vice-President, who are elected every four years by the Navajo people (SW Strategy, 2003 - S05050302).

NAVAJO CHAPTERS

The Tribal government structure consists of 110 chapters, representing all reservation areas and Navajo communities. The 110 chapters are the local form of government. “Although it would be misleading to consider a chapter as a county, they are more significant than a township or municipality, and are most comparable to counties within a state” (McKenzie, 1999 - S01280302). Each chapter elects a President, Vice-President, Secretary-Treasurer, and Grazing Committee, Farm Board, and/or Land Board member to run the affairs of the local chapter community. Community meetings are held in the chapter houses and the members vote on issues such as home site leases and land use plans. Chapters exercise authority which is delegated by the Navajo Nation government over tribal members, and land/assets within their boundaries (SW Strategy, 2003 - S05050302).

Each of the Navajo Nation Chapters has developed a website, with useful information in their Chapter Profiles and chapter demographics (NNDES, 2006 - S02060604). A Navajo Nation Chapters Directory website is under development at www.navajochapters.org with links to each Chapter’s website.

BUREAU OF INDIAN AFFAIRS (BIA) AGENCIES

There are five (5) BIA agencies within the Navajo Nation: Chinle, Eastern Navajo, Fort Defiance, Shiprock and Western Navajo. The top map in Figure 5 shows the boundaries of the BIA agencies. These agencies are administrative designations created by the BIA primarily for management of reservation land bases. The administrative hierarchy within the BIA divides the United States into different “Area Offices,” which are in turn divided into agencies. In recent years, the agency boundaries have become important to the Navajo Nation for its governmental activities, particularly in planning and service delivery. The agency has become incorporated into the Navajo Nation political system. Each of the agencies have a council which considers issues common to the chapters within that agency. Further, the agency geographical subdivision is used in making reports to the U.S. Department of Interior and the Congress (McKenzie, 1999 - S01280302).

BIA LAND MANAGEMENT DISTRICTS

In 1936, the Commissioner of Indian Affairs established land management districts within the Navajo Indian Reservation. There are 22 BIA Land Management Districts on the Navajo Nation. The bottom map in Figure 5 shows the boundaries of the BIA Districts. District 6 is the Hopi Reservation. District 22 (Alamo) is not shown on the map

STATES AND COUNTIES

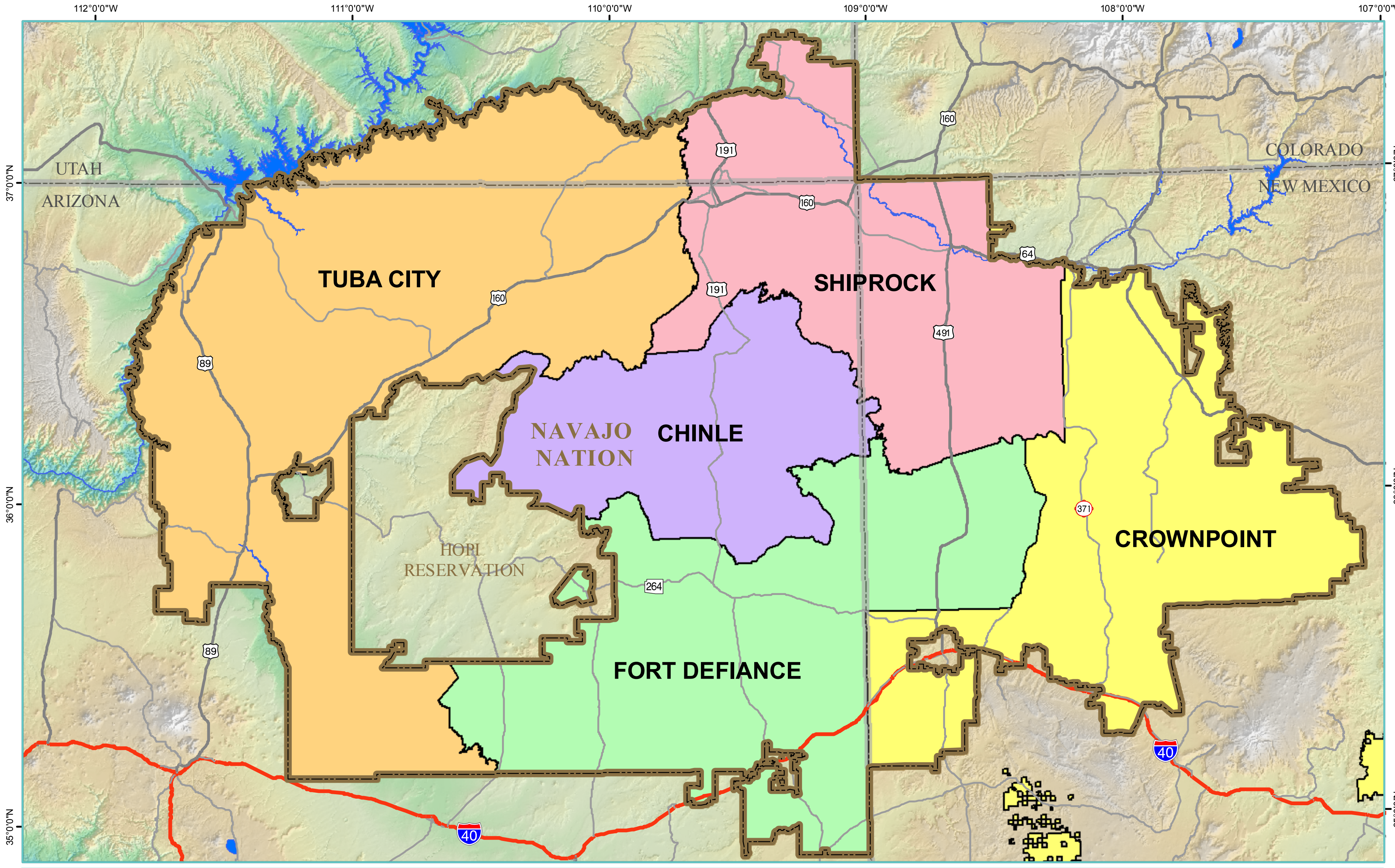
The Navajo Nation is the largest Indian reservation. It spans eleven (11) counties within Arizona, New Mexico, and Utah:

Arizona Counties
  Apache, Navajo, and Coconino

New Mexico Counties
  Bernalillo, Cibola, McKinley, Rio Arriba, San Juan, Sandoval, and Socorro

Utah County
  San Juan

States and counties have limited jurisdiction over the Navajo Nation, and only as provided by Federal law. On the Navajo Nation, only Federal and tribal laws apply to members of the Tribe (BIA, 2001 - S05050301).



NAVAJO NATION AGENCIES

Source

Navajo Nation Agency boundaries are from the Navajo Land Department.

Filename: DB/Boundary/Navajo_Nation.shp

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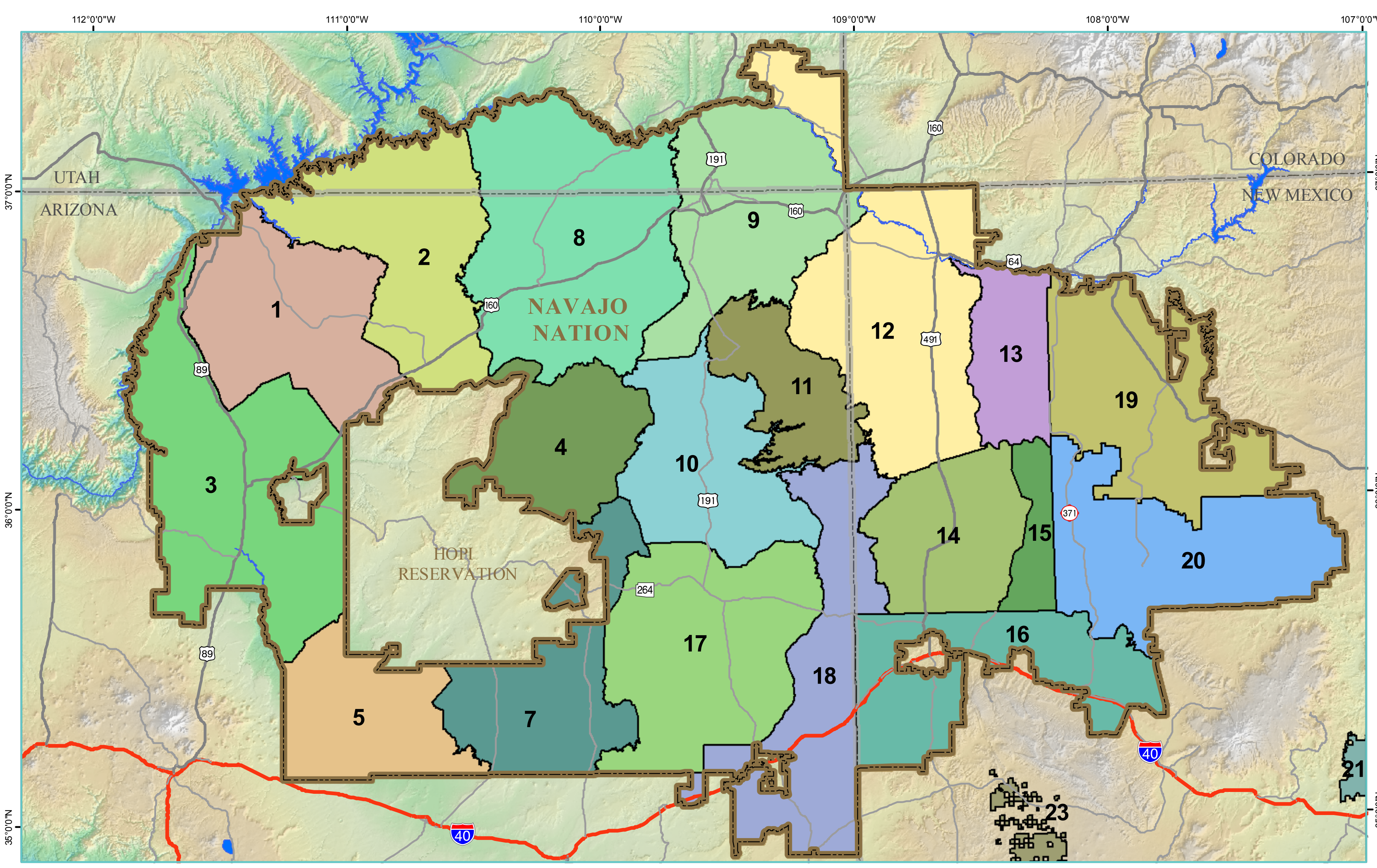
Map Scale 1:1,900,000

Legend

AGENCY

- Chinle
- Crownpoint
- Fort Defiance
- Shiprock
- Tuba City



NAVAJO NATION DISTRICTS

Source

Navajo Nation District boundaries are from the Navajo Land Department.

Filename: DB/Boundary/Navajo_Nation.shp

0 50 Miles

Map Scale 1:1,900,000

Legend

16 District

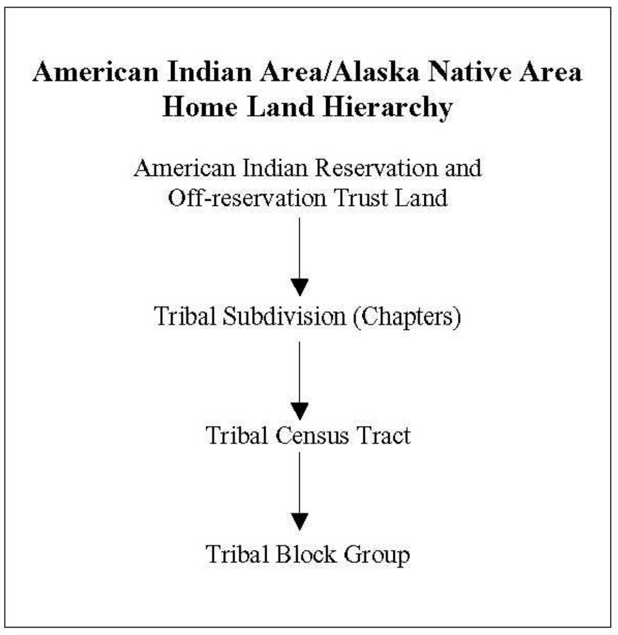
Figure 5. Navajo Nation Agencies and Districts.

NAVAJO NATION DEMOGRAPHICS

Since the first census in 1790, the Federal Government has conducted a census of the U.S. population and its housing units every ten years. However, it was not until 1860 that American Indians were counted in the census as a separate population category. In 1960, the U.S. Census Bureau made many changes in its methods of enumeration in an effort to acquire a more accurate and complete count for American Indians and Alaska Natives (AIANA) (U.S. Census Bureau, 1999 - S05070302). The Census Bureau began to report data systematically for American Indian reservations in conjunction with the 1970 census. The Census Bureau used the reservation boundaries shown on its enumeration maps, which proved in many cases to be inaccurate and incomplete. For the 1980 census, the Census Bureau attempted to improve reservation boundary information and worked with the Bureau of Indian Affairs (BIA) to obtain more accurate maps. In an effort to further improve enumeration for the 1990 census, the Census Bureau increased its collaboration throughout the 1980's with the American Indian and Alaska Native population by creating the Tribal Governments Liaison Program. The Census Bureau and the BIA signed a memorandum of understanding to achieve a more inclusive exchange of boundary information between the two agencies and the tribal authorities. This agreement provided the framework for the Tribal Review Program. The Census Bureau obtained boundary maps from the BIA, which were then provided to the tribal governments for review. A process of reviews and boundary certifications continued until mid-1989. The Census Bureau developed Tribal Review Maps, which were sent to the tribes for approval and final certification by the BIA. The Tribal Review Program improved the accuracy of the reservation and trust land information used for the 1990 census (U.S. Census Bureau, 1994—S05070301). For Census 2000, the Census Bureau relied entirely on Navajo Nation officials to review the legal boundaries already in the Census Bureau's records. The BIA was asked to participate only if the Census Bureau needed additional information (U.S. Census Bureau, 2002 - S05070303).

CENSUS GEOGRAPHIC AREAS FOR AMERICAN INDIAN AND ALASKA NATIVE AREAS (AIANA)

The Census Bureau tabulates and publishes population and housing census data for several geographic areas that cover AIANA areas. The two primary types of AIANA geographic areas on the Navajo Nation are reservation lands and trust lands. In addition, the 1990 Census included programs to allow tabulating AIANA census data by smaller geographic areas. These included: tribal subreservations, census tracts, and block groups.



<u>Reservations and Trust Lands</u>

American Indian reservations are areas with boundaries established by treaty, statute, and/or executive or court order. The Navajo Nation also has trust lands, which are real property held in trust by the Federal Government. Trust lands may be located within a reservation or outside of a reservation. However, the Census Bureau recognizes and tabulates data separately only for the inhabited off-reservation trust lands; on-reservation trust lands are included as part of the Navajo Nation reservation. As with reservations, tribal trust lands may cross state boundaries. The Census Bureau first reported data for tribal trust lands in conjunction with the 1980 census. For the 2000 Census, tribal subreservations were changed to American Indian Tribal Subdivisions, which allow the tabulation and presentation of census data that are more useful to the Navajo Nation.

<u>Tribal Census Tract</u>

Tribal census tracts are small, relatively permanent statistical subdivisions of the Navajo Nation and its off-reservation trust land. The optimum size for a tribal census tract is considered to be about 2,500 people; it must contain a minimum of 1,000 people.

<u>Tribal Block Group</u>

A tribal block group (BG) is a cluster of census blocks that are within a single tribal census tract. The optimum size for a tribal BG is 1,000 people; it must contain a minimum of 300 people.

<u>Census Designated Places (CDP)</u>

Census Designated Places, or CDPs, are population concentrations that function as a community, are locally recognized as such, but are not legally incorporated. To recognize the significance of unincorporated communities located on American Indian reservations, the Census Bureau lowered the minimum population size for such CDPs to 250 people for the 1990 census.

<u>Tribal Subdivisions</u>

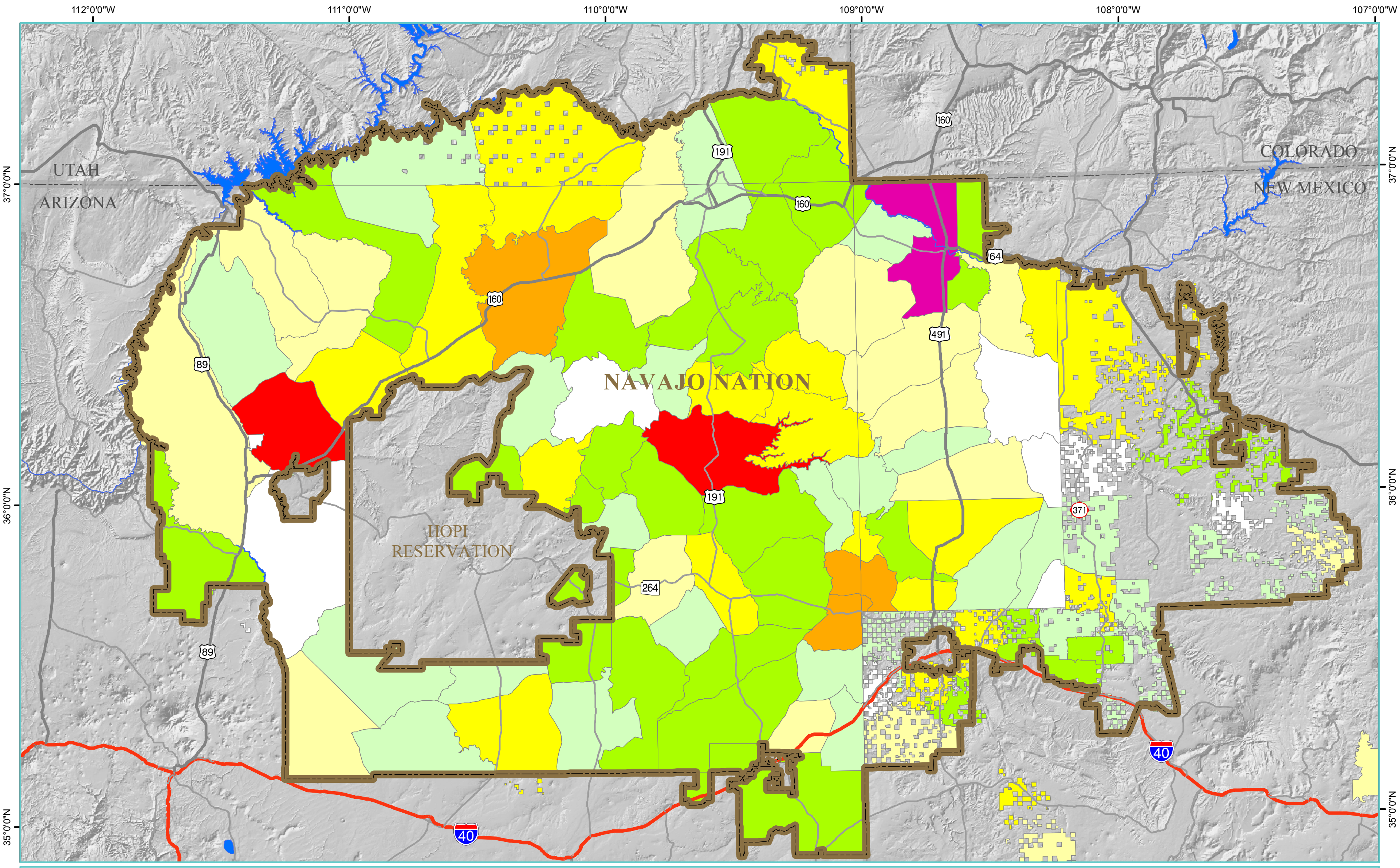
On May 4, 1999 Taylor McKenzie, the Navajo Nation Vice-President, testified before the U.S. Senate Committee on Indian Affairs in Washington, D.C. regarding the views of the Navajo Nation on the 2000 Census. He stressed the importance that the mapping used by the Census Bureau needed to reflect the political units used by the Navajo Nation - namely, Chapters and Agencies (McKenzie, 1999 - S01280302). Tribal subdivisions were implemented in the 2000 Census. Chapters make up the tribal subdivisions for the Navajo Nation. Users of these data should note that the Tribal Subdivision boundaries used in the 2000 Census are not the same as the Chapter boundaries provided by the Navajo Land Department .

2000 CENSUS DEMOGRAPHICS

The 2000 Census reports the total population on the Navajo Nation Reservation and Off-Reservation Trust Land as 180,462 (U.S. Census Bureau, 2000 - S05070304). Figure 6 shows the total population for the Navajo Nation by Tribal Subdivision from the 2000 Census. There are differences between some of the chapter boundaries and the tribal subdivisions used by the Census Bureau. The tribal subdivisions with the highest populations are Shiprock, Kayenta, Chinle, Tuba City, and Fort Defiance.

<u>Navajo Nation Demographics</u>

Figure 6 provides "DP-1 Profile of General Population and Household Characteristics: 2000 Census" for the Navajo Nation Reservation and Off-Reservation Trust Land, AZ-NM-UT (U.S. Census Bureau, 2000—S05070304). According to the 2000 Census, the total population for the Navajo Nation was 180,462. The median age was 24 years. There were 47,603 occupied households, 21,141 vacant housing units and 11,126 seasonal, recreational, or occasional use on the Navajo Nation. The average size of a household was approximately 3.8 people.



2000 CENSUS - NAVAJO NATION
TOTAL POPULATION BY TRIBAL SUBDIVISION

Source

Population by tribal subdivision data is from the U.S. Census Bureau - 2000 Census.

Filename: DB/Cultural/nn_tribal_sub_w_pop.shp.

0 50 Miles

Map Scale 1:1,900,000

Legend

TOTAL POPULATION

- 0 - 500
- 501 - 1000
- 1001 - 1500
- 1501 - 2000
- 2001 - 4000
- 4001 - 7500
- 7501 - 9000
- 9001 - 10000

SUBJECT	NUMBER	PERCENT
TOTAL POPULATION	**180,462**	**100**
SEX AND AGE		
Male	88,469	49
Female	91,993	51
Under 5 years	17,364	9.6
5 to 9 years	21,373	11.8
10 to 14 years	22,967	12.7
15 to 19 years	18,742	10.4
20 to 24 years	11,912	6.6
25 to 34 years	22,202	12.3
35 to 44 years	24,470	13.6
45 to 54 years	17,316	9.6
55 to 59 years	6,182	3.4
60 to 64 years	5,402	3
65 to 74 years	7,691	4.3
75 to 84 years	3,515	1.9
85 years and over	1,326	0.7
Median age (years)	**24**	**(X)**
18 years and over	106,432	59
Male	50,897	28.2
Female	55,535	30.8
21 years and over	97,395	54
62 years and over	15,707	8.7
65 years and over	12,532	6.9
Male	5,401	3
Female	7,131	4

SUBJECT	NUMBER	PERCENT
HOUSEHOLDS BY TYPE		
Total households	**47,603**	**100**
Family households (families)	37,903	79.6
With own children under 18 years	22,989	48.3
Married-couple family	22,708	47.7
With own children under 18 years	14,614	30.7
Female householder, no husband present	11,759	24.7
With own children under 18 years	6,441	13.5
Nonfamily households	9,700	20.4
Householder living alone	8,841	18.6
Householder 65 years and over	2,697	5.7
Households with individuals under 18 years	28,087	59
Households with individuals 65 years and over	9,924	20.8
Average household size	3.77	(X)
Average family size	4.36	(X)
HOUSING OCCUPANCY		
Total housing units	**68,744**	**100**
Occupied housing units	47,603	69.2
Vacant housing units	21,141	30.8
For seasonal, recreational, or occasional use	11,126	16.2
HOUSING TENURE		
Occupied housing units	**47,603**	**100**
Owner-occupied housing units	36,092	75.8
Renter-occupied housing units	11,511	24.2
Average household size of owner-occupied unit	3.78	(X)
Average household size of renter-occupied unit	3.75	(X)

(X) Not applicable

Source: U.S. Census Bureau, Census 2000 Summary File 1, Matrices P1, P3, P4, P8, P9, P12, P13, P,17, P18, P19, P20, P23, P27, P28, P33, PCT5, PCT8, PCT11, PCT15, H1, H3, H4, H5, H11, and H12.

DP-1 PROFILE OF GENERAL POPULATION AND HOUSEHOLD CHARACTERISTICS: 2000 CENSUS
Navajo Nation Reservation and Off-Reservation Trust Land, AZ-NM-UT

Data from Census 2000 Summary File 1 (SF1) 100-Percent Data
Filename: DB/Demog/NN_2000Census_pop.xls

Figure 6. Navajo Nation Census 2000 Population and Households.

STRUCTURES

For the purposes of this NAUM Project, structures within one (1) mile of an AUM were mapped as an indicator of the target population locations. The target population consists of those people who use target wells or surface water for drinking water, eat food taken from impacted livestock or fisheries, or are regularly present on an AUM site or live within target distance limits.

For the purposes of assessing the potential target population, it is important to know where people live, work, go to school, and routinely gather. The locations of current residences were not readily available for the Navajo Nation. Existing USGS topographic maps include many buildings and other structures of interest. However, a majority of these maps are over 20 years old and require conversion into a suitable GIS format for analysis. More recent USGS Digital Orthophoto Quarter Quadrangles (DOQQs) were available and were used as a basis to map buildings and other structures by photointerpretation. The DOQQs were generated from aerial photography acquired in 1997 and 1998. For a small number of features, the older topographic maps were used as an interpretation aid. The interpretation of structures was limited due to the dates of the DRGs and DOQQs, which ranged in age from 8 to 20 years. Structures that were constructed after the date of the DRG or DOQQ were not present. In some cases, structures that were present at the time the DRGS or DOQQs were generated do not exist today.

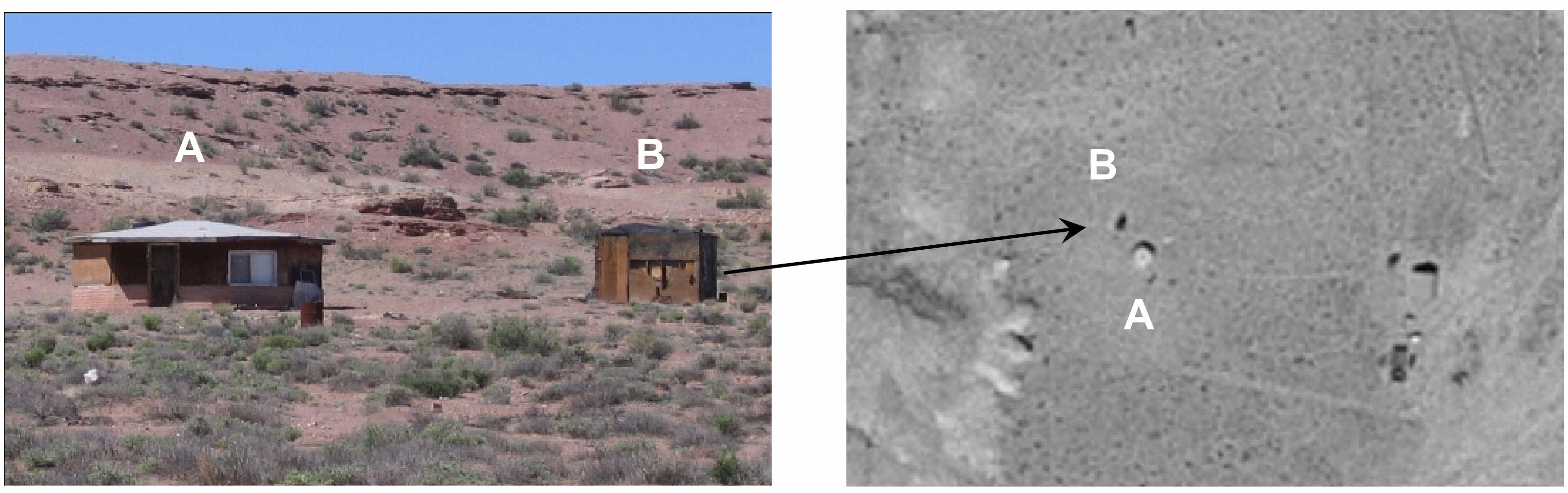


Figure 7. Photo Key Showing Ground Photo and Corresponding DOQQ Image of Structures.

The Navajo Tribal Utility Authority (NTUA) provided point locations for utility meters for the NTUA service areas within five (5) miles of a mapped AUM. The meter locations were collected by NTUA using Global Positioning System (GPS) equipment. It was assumed that where there were water, gas, or electric meters there was probably some type of structure present. The NTUA meter data was very useful in verifying the location of structures that were mapped from the DOQQs. The meter data were also used to include an "assumed structure" category, which designates the locations of structures that may have been constructed after 1997. Use of the NTUA meter location data was limited to this structures mapping effort, and distribution of the data was not permitted. Color DOQQs flown in 2005 were available for New Mexico and were used for structure mapping in the Eastern AUM Region.

More recent aerial photography (2005) was flown by the U.S. Bureau of Indian Affairs (BIA), and DOQQs were generated. These DOQQs were not available for distribution by the BIA for use in this project. However, when they are made available, these color DOQQs should provide a useful source for updating and photo-verifying the structures dataset.

Photo keys were developed to assist with the interpretation of structures and related features (Figures 7 and 8). However, it was not possible to accurately distinguish residences from other types of structures by photointerpreting the DOQQ imagery. Some structures that were mapped may be large sheds or other non-residential structures, and some may be seasonal residences and not occupied full-time. All of these structures, however, are indicative of locations where people might be present. These structures were used as an indicator for the probable location of the target population for the soil pathway and air pathway assessments. A map of structures within one (1) mile of an AUM site is shown on Figure 9. This dataset is provided on the GIS Data DVD (DB/Cultural/NN_Structures_1mi.shp). Also shown on Figure 9 are the locations of Chapter Houses, which was provided by the Navajo Land Department (NLD), and is included on the GIS Data DVD (DB/Cultural/nnchppts.shp). NLD used color and black and white DOQQs, Chapter boundaries, surface roads, and Division of Community Development chapter websites to update the locations of the Chapter Houses.

Another source of information about where people live on the Navajo Nation is the Geographic Names Information System (GNIS), which was developed by the U.S. Geological Survey in cooperation with the U.S. Board on Geographic Names. This point dataset provides the locations and names of populated places for the Navajo Nation and the surrounding region (DB/Cultural/NN_Pop_Places.shp).

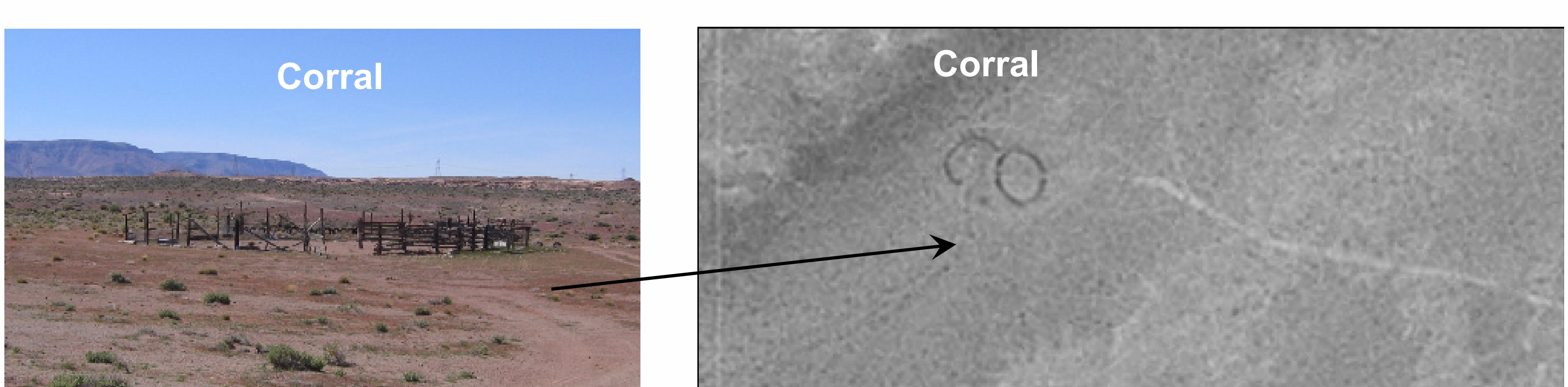
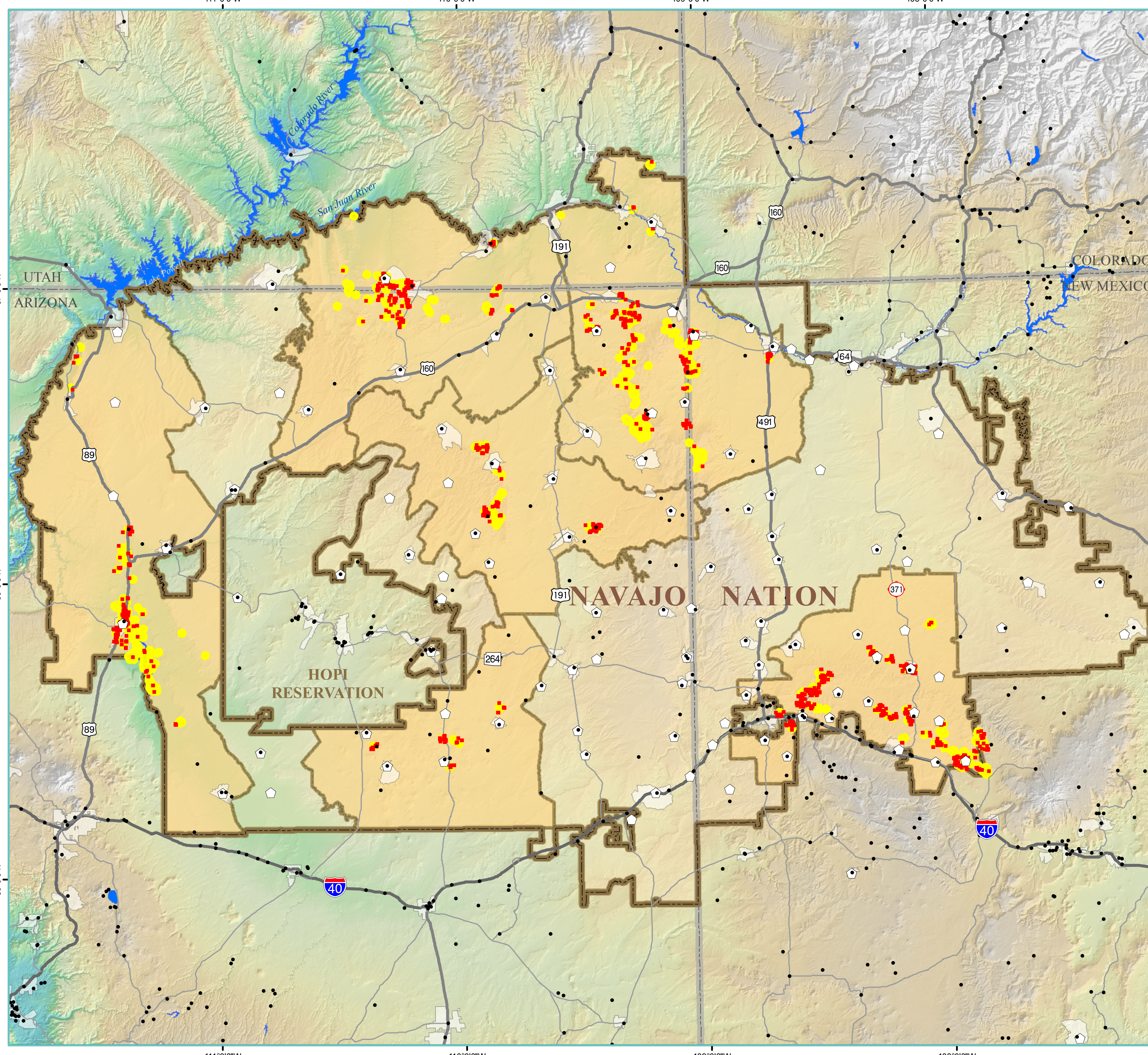


Figure 8. Photo Key Showing Ground Photo and Corresponding DOQQ Image of Corrals.



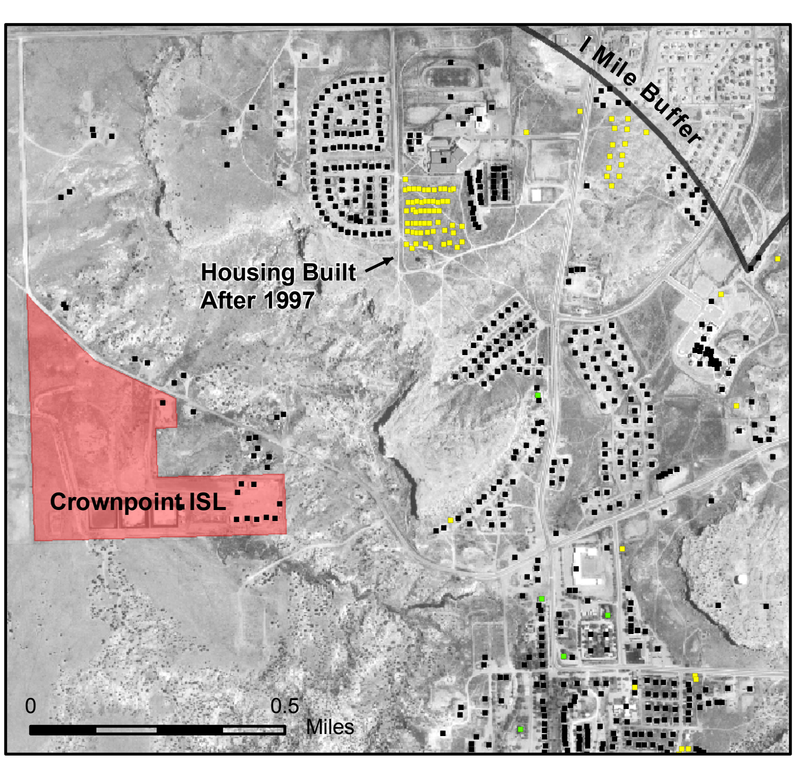
ABANDONED URANIUM MINES AND THE NAVAJO NATION

STRUCTURES WITHIN 1 MILE OF AUMS AND OTHER POPULATED PLACES

N
W E
S

0 50 Miles

Map Scale 1:1,750,000



Community of Crownpoint, which is proximal to the Crownpoint In-Situ Leach facility. Structures were mapped from 1997 orthophotography (shown in black). "Assumed structures" (shown in yellow) were added from utility meter locations provided by the Navajo Tribal Utility Authority (NTUA). These structures are not present on the 1997 orthophotography.

Legend

STRUCTURES AND POPULATED PLACES

- Structures within 1 Mile of an AUM
- Chapter Houses
- GNIS Populated Places
- Designated Census Place
- One Mile Buffer Around an Abandoned Uranium Mine
- Navajo Nation and AUM Region Boundaries

Sources

Structures within one (1) mile of an AUM were photo-interpreted by TerraSpectra Geomatics.
Filename: DB/Cultural/NN_Structures_1mi.shp

Chapter House locations from the Navajo Land Department - GIS Section.
Filename: DB/Cultural/nnchppts.shp

Populated places points were extracted from the Geographic Names Information System (GNIS) database developed by the U.S. Geological Survey.
Filename: DB/Cultural/NN_Pop_Places.shp

Designated Census Place from the U.S. Census Bureau - 2000 Census.
Filename: DB/Demog/nn_censuspl.shp

Figure 9. Structures Within 1 Mile of AUMs and Other Populated Places.

TRANSPORTATION

Federal and state highways that provide access to the Navajo Nation include: U.S. Interstate 40 to the south, U.S. Highway 89 to the west, U.S. Highway 160 to the north, and U.S. Highway 491 to the east. A network of state highways cross the Navajo Nation and are shown in Figure 13. Highway data for the Navajo Nation was extracted from the 2002 National Transportation Atlas Database, (NTAD) and is provided on the GIS Data DVD (DB/Trans/NN_Highways.shp).

Most of the roads on the Navajo Nation are unpaved and are part of the Indian Reservation Roads (IRR) Program. IRR are public roads which provide access to and within Indian reservations, Indian trust land, and restricted Indian land. According to the 2000 BIA Road Inventory Database, the Navajo IRR system consists of 9,826 miles of public roads. Of that, the Navajo Nation maintains 1,451 miles of paved road, and 4,601 miles of gravel and dirt roads. Weather conditions often make many of those roads impassable. In the winter, snow and rain may prohibit access. Because of the prolonged drought, some of these roads have become nearly impassable due to sand dunes, rocky surfaces and deep holes (Navajo Nation, 2002 - S05240717).

The Navajo Nation's roads have been administered by the BIA Navajo Area Branch of Roads (BOR). Figure 13 shows Indian Service Routes on the Navajo Nation. These paved BIA routes are from a GIS dataset of roads obtained from the BIA in 2003. Many of the paved roads were modified by photointerpreting digital orthophotos to adjust or add road features. Figures 10 and 11 show before and after adjustments based on photo interpretation of DOQQs. These modifications were only made to paved roads in Chapters with mapped AUMs. The adjusted dataset is provided on the GIS Data DVD (DB/Trans/NN_Paved.shp).

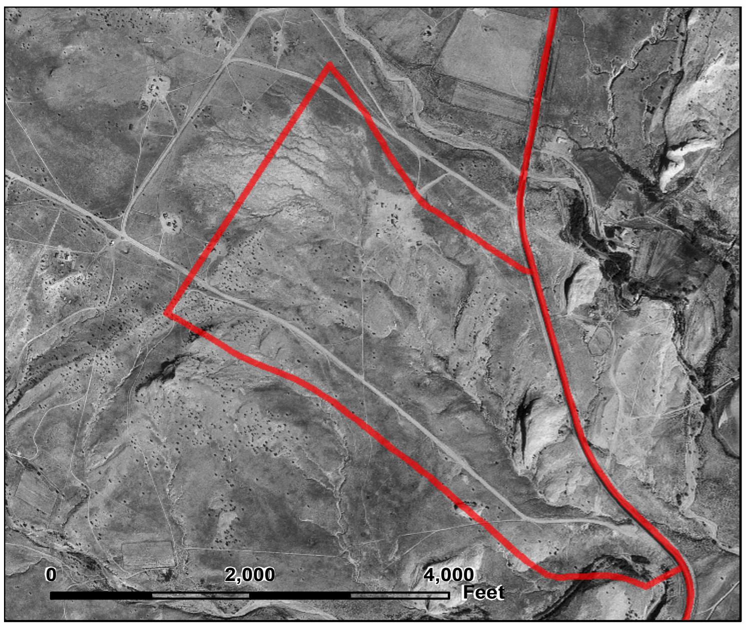


Figure 10. Example of Unadjusted BIA Roads.

Figure 11. Example of Adjusted BIA Roads.

The Navajo Department of Transportation (NDOT) was created in 1986 by the Navajo Nation Council. NDOT is working to establish the Navajo Nation's road program, which includes development and maintenance of an IRR GIS database. BIA contracted to have aerial photography flown for the Navajo Nation in 2005, and new color orthophotography was generated. The new orthophotography, along with Global Positioning System (GPS) field measurements, will allow development of a more accurate IRR database.

The location of roads has significance to the NAUM Project. The process of locating AUMs was often assisted by following roads on the DOQQs and DRGs. This was particularly true for productive AUMs that required the ore to be hauled by truck. Haulage roads may also have significance as a potential contaminant source. In Figure 12, the Monument No. 2 AUM (outlined in black) is shown with the DOE aerial radiation survey excess Bismuth-214 results. Of note are the elevated excess Bismuth-214 contours that extend beyond the boundary of the AUM and that are coincident with the haulage road.

During the 1950's the U. S. Atomic Energy Commission (AEC) funded a program to construct and/or improve access roads to exploration and mining areas. Five projects in Arizona were on the Navajo Nation in Apache County. These roads provided better access to several uranium mining areas, especially the Lukachukai Mountains, eastern Carrizo Mountains, and the Cane Valley area of Monument Valley (Chenoweth, 1989 - S10100213).

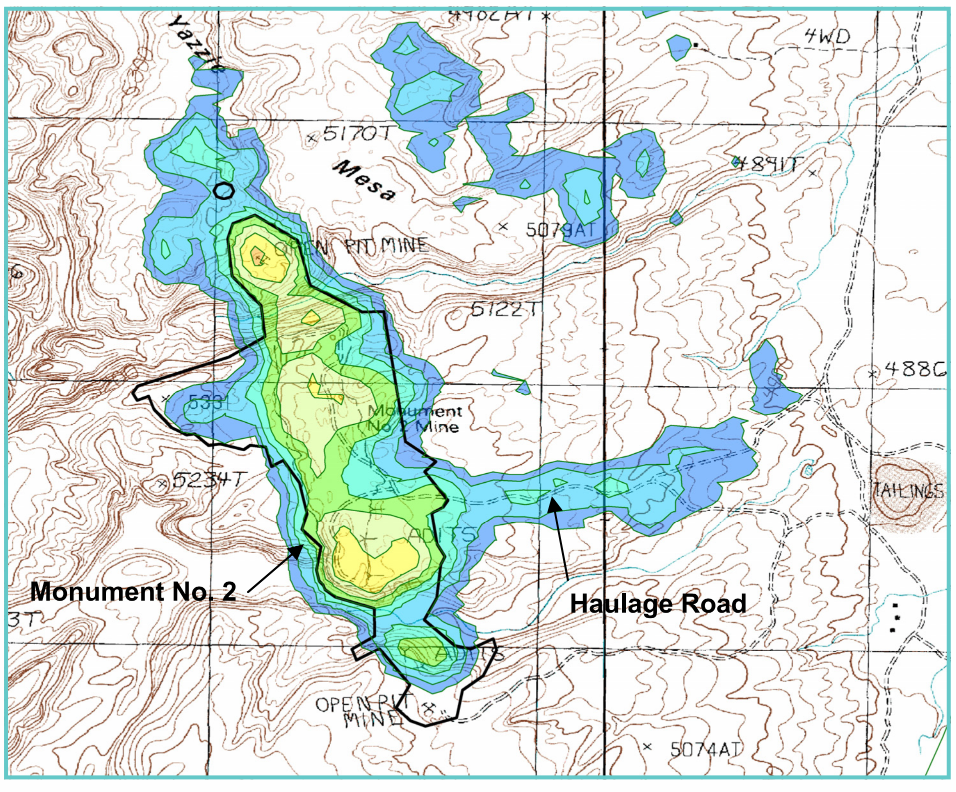
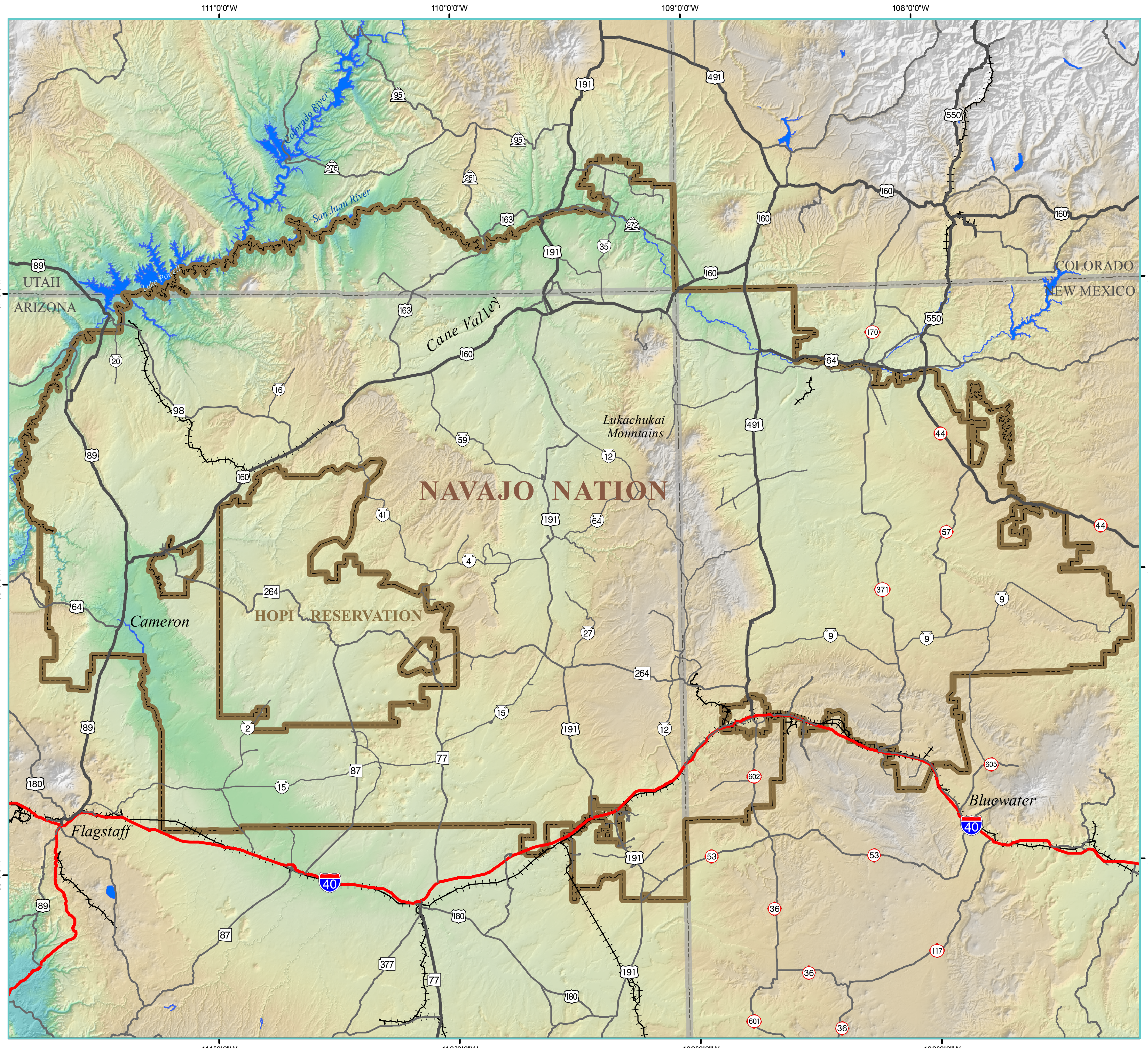


Figure 12. Elevated Excess Bismuth-214 Along Haulage Road.

Railways also played a role in the transport of uranium ore from the Navajo Nation. For example, shipments to the Bluewater ore-buying station were made from some AUMs in the Cameron area. The ore was trucked to Flagstaff and shipped by the Atkinson Topeka and Santa Fe Railway to a siding near Bluewater, where the ore was transferred to trucks for the short haul to the buying station (Chenoweth, 1993 - S10100239). These ore transfer locations may have residual radionuclides, similar to those found at the Cove and Climax Transfer Stations.

Railways that are on or near the Navajo Nation are shown on Figure 13. These data are from the Federal Railroad Administration (FRA) and the Bureau of Transportation Statistics NTAD and are provided on the GIS Data DVD (DB/Trans/NN_rail.shp).



ABANDONED URANIUM MINES AND THE NAVAJO NATION

TRANSPORTATION

0 50 Miles

Map Scale 1:1,750,000

Ore trucks, Lukachukai Mountains, Arizona. Photo courtesy of William L. Chenoweth

Legend

Railroad

ROADS AND ROUTE SHIELDS

- U.S. Interstate Route
- U.S. Route
- Arizona State Route
- New Mexico State Route
- Utah State Route
- Indian Service Route

Sources

Highways for the Navajo Nation were extracted from the National Highway Planning Network, developed by the Federal Highway Administration (FHWA) and the Bureau of Transporation Statistics (BTS) National Transportation Atlas Database, 2002. Filename: DB/Trans/NN_Highways.shp

Paved roads are from the U.S. Bureau of Indian Affairs (BIA) and modified by adjustment or photointerpretation of DOQQs. Changes were only made for Chapters that have AUMs.
Filename: DB/Trans/NN_Paved_Roads.shp

Railroads are from the Federal Railroad Administration and BTS.
Filename: DB/Trans/NN_rail.shp

Figure 13. Paved Roads and Railroads On and Near the Navajo Nation.

CLIMATE

Temperature, precipitation, and wind conditions that characteristically prevail in a region play an important role in contaminant pathway assessments. These climate factors on the Navajo Nation are discussed in this section.

Other climate impacts are related to the drought conditions the Navajo Nation has been experiencing in recent years. Drought and temperature increases due to climate change affect the amount of vegetation growing on sand dunes. Sand dunes cover approximately one-third of the semi-arid Navajo Nation on the southern Colorado Plateau. Sand supplies here are abundant from both sandstone bedrock and dry river channels. In this area winds capable of moving sand are dominantly from the southwest (Figure 14). The risk of sand dune mobilization within this region is high given: 1) current severe drought conditions; 2) climate variability based on known historic records (such as the drought during the early 20th century); 3) the overall decrease in regional precipitation for this last century; 4) the apparent drying trend on the Navajo Nation, and; 5) the possibility of climate change. Current work indicates that reactivation of stabilized sand is occurring in many areas of the Navajo Nation where the vegetation growing on the dunes, and holding them in place, are dying. Dune mobility is a cause for concern, and is today inundating housing and causing transportation problems. It also may be contributing to a loss of rare and endangered native plants and grazing land, and lower air quality from periodic dust storms (Hiza, 2003 - S05270701). These same climatic variables may have similar effects on vegetation cover that may be stabilizing wind-blown dust from AUM debris or soil cover at AUM reclamation sites. This indicates that the air pathway may take on greater importance as desertification increases.

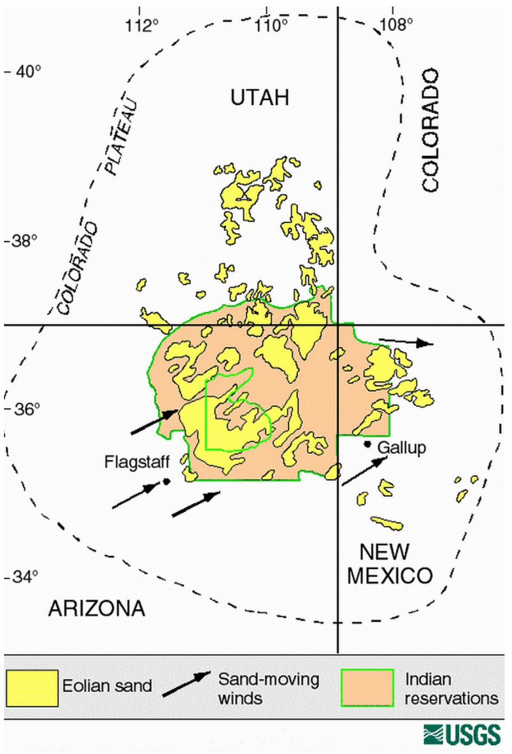


Figure 14. Location of Eolian Sand and Direction of Wind on the Navajo Nation (from Hiza, 2003 - S05270701).

PRECIPITATION

Precipitation is an important parameter to consider when evaluating potential migration pathways. Heavy precipitation provides a driving force to carry hazardous substances through the soil to the ground water, or to carry hazardous substances away from a site through runoff. Data on the intensity, duration, and frequency of storms is needed to calculate the volume of surface water run-on or run-off. If there is flooding potential, the flood characteristics (e.g. stagnant backwater or scour potential due to flow) would be useful information for assessing AUM sites. Conversely, dry conditions can enhance the wind erosion potential for certain soil types, increasing the potential for air transport.

Precipitation throughout Arizona and New Mexico is locally governed to a large extent by elevation and orographic effects and the season of the year. From November through March storm systems from the Pacific Ocean cross the state. These winter storms occur across the Navajo Nation in the higher mountains, where much of the winter precipitation falls as snow. Summer rainfall begins early in July and usually lasts until mid-September. Summer rains fall almost entirely during brief, but frequently intense thunderstorms. The general southeasterly circulation from the Gulf of Mexico brings moisture from these storms into the state. Strong surface heating, combined with orographic lifting as the air moves over higher terrain, causes air currents and condensation. Because precipitation usually is relatively intense, some local runoff and flash flooding result (Cooley et al., 1969 - S10290201).

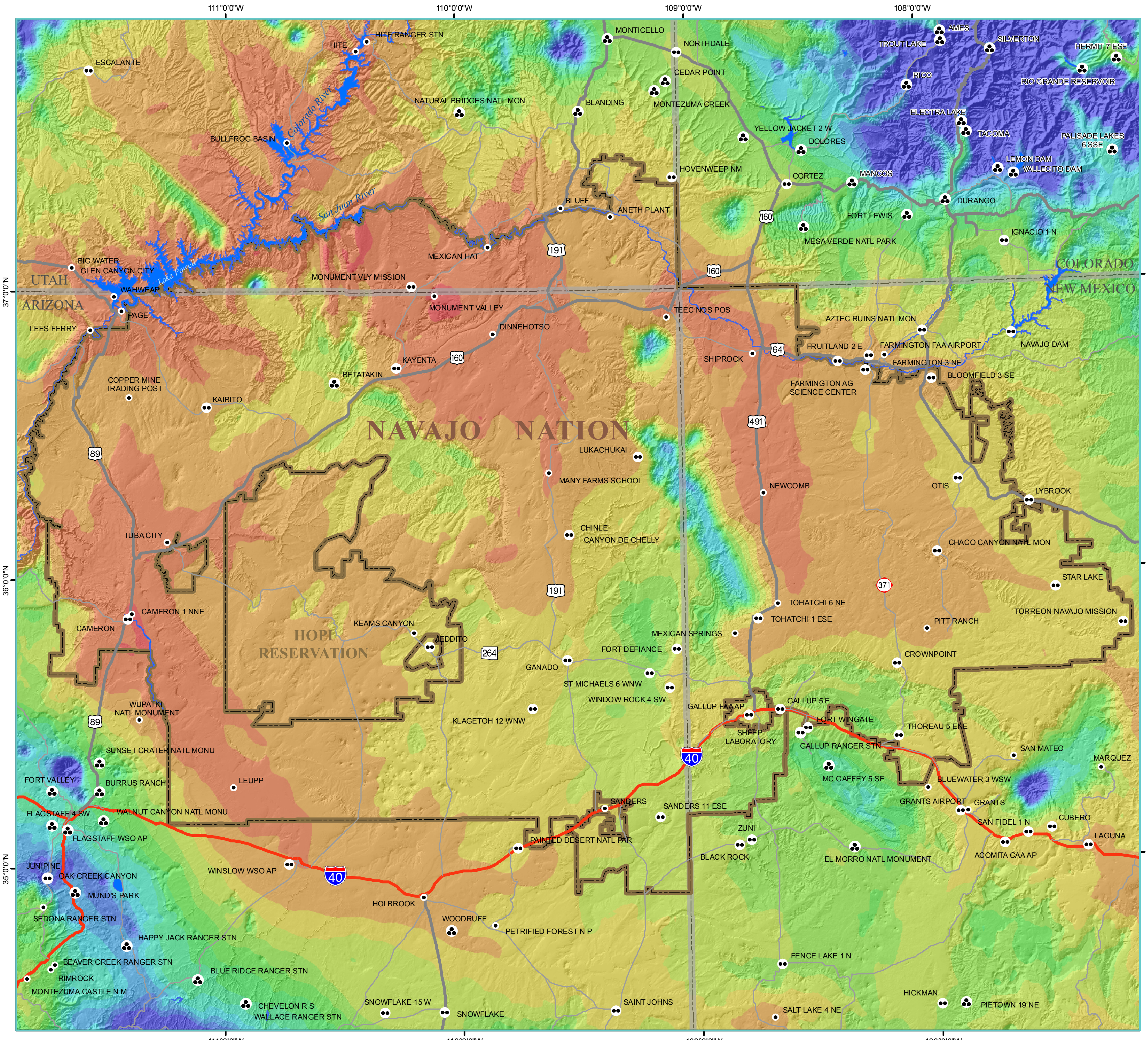
Weather stations are sparsely and unevenly spaced throughout much of Arizona and New Mexico. Factors such as site location, density of distribution, types of equipment, and observer bias all affect the precision, accuracy, and utility of resulting climate data. The National Weather Service (NWS) operates three weather stations in Arizona (Flagstaff, Phoenix, and Tucson), and one station in New Mexico (Albuquerque). Additionally, there is a network of cooperative weather stations that regularly gather and report temperature and precipitation data. The coverage and total number of cooperative weather stations varies over the state. Arizona's tribal lands, which constitute a sizable portion of the total land area of the state, are underrepresented as are high-elevation areas in general (Sheppard et al, 1999 - S07280303).

There are many methods of interpolating climate data from monitoring stations to grid points. Some methods provide estimates of acceptable accuracy in flat terrain, but few have been able to adequately explain the extreme, complex variations in climate that occur in mountainous regions. Significant progress in this area has been achieved through the development of PRISM (Parameter-elevation Regressions on Independent Slopes Model). PRISM is an analytical model that uses point data and an underlying grid such as a digital elevation model (DEM) for a 30 year climatological average (e.g. 1971- 2000 average) to generate gridded estimates of monthly and annual precipitation and temperature (as well as other climatic parameters). PRISM is well suited to regions with mountainous terrain, because it incorporates a conceptual framework that addresses the spatial scale and pattern of orographic processes, where air masses cool as they gain elevation, resulting in precipitation. The PRISM Group at Oregon State University developed a spatially gridded average annual precipitation for the climatological period 1971-2000 that covers the Navajo Nation.

Distribution of the point measurements to a spatial grid was accomplished using the PRISM model. The PRISM Group at OSU used point estimates of precipitation from some or all of the following sources: 1) National Weather Service (NWS) Cooperative (COOP) stations, 2) Natural Resources Conservation Service (NRCS) SNOTEL, 3) United States Forest Service (USFS) and Bureau of Land Management (BLM) RAWS Stations, 4) Bureau of Reclamation (AGRIMET) stations, 5) storage gauges, 6) NRCS Snowcourse stations, 7) other State and local station networks, 8) estimated station data, 9) upper air stations, and 10) NWS/Federal Aviation Administration (FAA) Automated surface observation stations (ASOS). Grids were modeled on a monthly basis and the annual grids of precipitation were produced by averaging the monthly grids, and summing for precipitation. The gridded PRISM average annual precipitation dataset was processed into contours using ESRI's Spatial Analyst software.[1] Polygons were generated and attributed with average annual precipitation range values as shown in Figure 15. This dataset is provided on the GIS Data DVD (DB/Climate/NN_Precipitation.shp).

The largely semi-arid Navajo Nation is shown in Figure 15 by the dominance of 4-12 inches of precipitation. The orographic effect can be seen on the Chuska and Carrizo Mountains and the Defiance Plateau where precipitation rises to 12-28 inches. Black Mesa, with an intermediate elevation, shows this same effect where precipitation rises to 18 inches annually.

[1] Mention of trade names, products, or services does not convey official EPA approval, endorsement, or recommendation.



ABANDONED URANIUM MINES AND THE NAVAJO NATION

NAVAJO NATION AVERAGE ANNUAL PRECIPITATION: 1971 - 2000 AND AVERAGE ANNUAL SNOWFALL

N
W E
S

0 50 Miles

Map Scale 1:1,750,000

Aerial photo of flooding after a heavy rain storm along the intermittent Moenkopi Wash near Tuba City, Arizona. Photo courtesy the U.S. Army Corps of Engineers (photo taken October 9, 2002).

Legend

AVERAGE ANNUAL PRECIPITATION (Inches)

4 - 6	18 - 20
6 - 8	20 - 22
8 - 10	22 - 24
10 - 12	24 - 26
12 - 14	26 - 28
14 - 16	28 - 30
16 - 18	>30

AVERAGE ANNUAL SNOWFALL (Inches)

- <10.0
- 10.0- 39.9
- >40

Source

The average annual precipitation on the Navajo Nation for the period 1971 - 2000 is from the PRISM Group at Oregon State University (OSU). PRISM (Parameter-elevation Regressions on Independent Slopes Model) is the analytical model that uses point data and an underlying grid such as a digital elevation model (DEM) for a 30 year climatological average (e.g., 1971- 2000 average) to generate gridded estimates of monthly and annual precipitation. PRISM is well suited to regions with mountainous terrain, because it incorporates a conceptual framework that addresses the spatial scale and pattern of orographic processes. The gridded data was converted to a polygon dataset by TerraSpectra Geomatics.

Filename: DB/Climate/NN_Precipitation.shp

Figure 15. Navajo Nation Average Annual Precipitation: 1971 - 2000.

CLIMATE (continued)

The U.S. Geological Survey (USGS) Navajo Nation Studies program is compiling meteorological information on precipitation type, intensity, and timing on the Navajo Nation. The purpose of these data collection efforts is to examine trends that may contribute to drought intensity. USGS plans to conduct infiltrometer work on alluvial deposits and to use soil moisture probes to evaluate relative effects of precipitation intensities, of both simulated and actual rainfall events, on soil moisture and infiltration (USGS, 2007 - S05220702).

The Navajo Nation Department of Water Resources is developing a database with stream gauge, climate, snow survey, and precipitation data. Inquiries concerning these data can be made to the Navajo Department of Water Resources, Water Management Branch, P.O. Drawer 678, Fort Defiance, Arizona 86504.

SNOWFALL

Snow accumulation can impact the effect of melting snow on soil water recharge, and the potential for contaminant transport at an AUM site. The mean annual snowfall is related to temperature, and more directly to physiography and altitude. However, wind, exposure, and other factors can cause variation in snow accumulation. Figure 16 shows the ranges of annual snowfall recorded at cooperative weather stations in and around the Navajo Nation. These data were acquired from the Western Regional Climate Center in tabular format (Table 1) and were processed into a GIS dataset that is provided on the GIS Data DVD (DB/Climate/NN_Snow.shp).

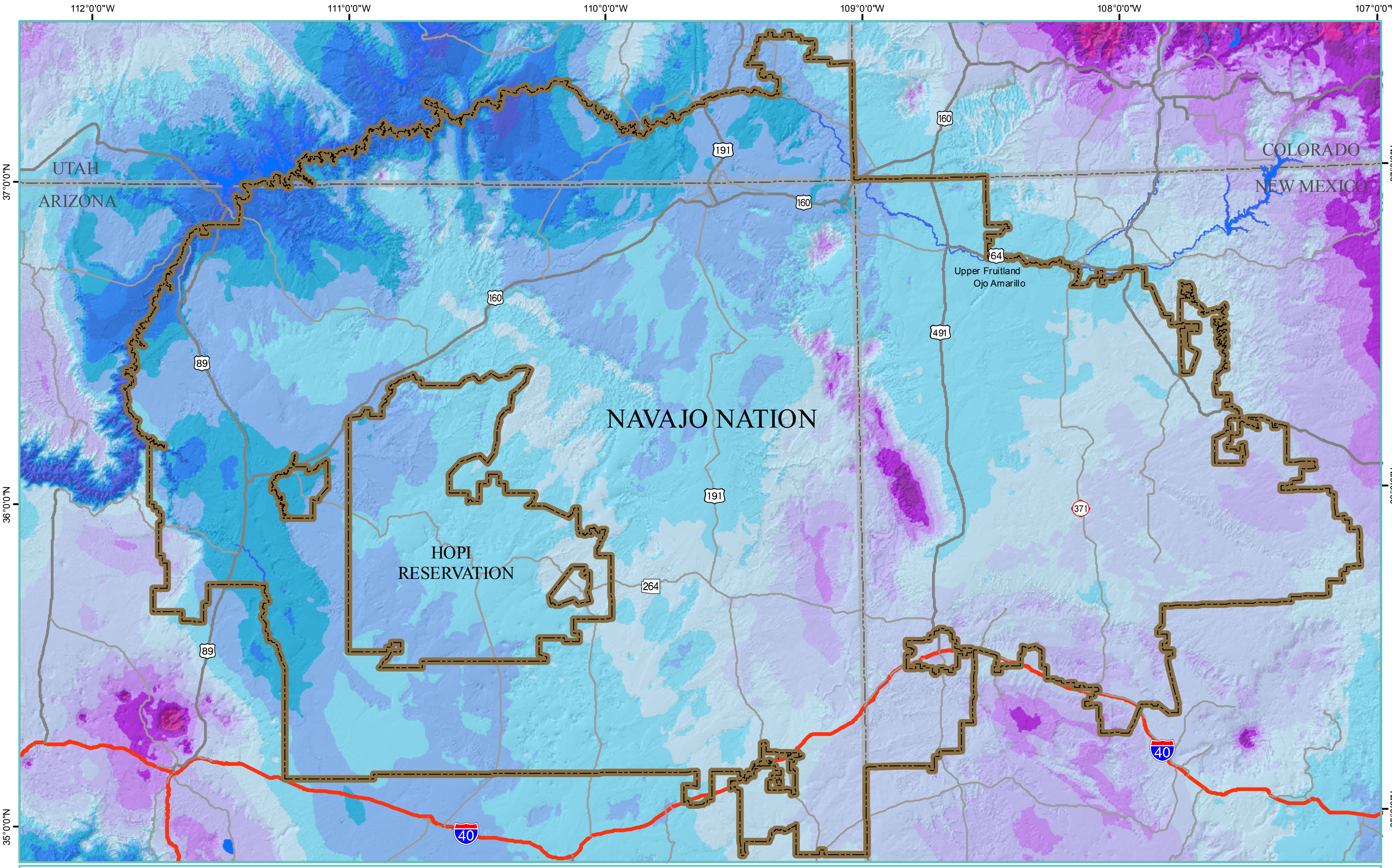
Table 1. Average Annual Snowfall On and Within 1 Mile of the Navajo Nation.

STATION ID	COOPERATIVE STATION NAME	State	Elev_ft	Start_Yr	End_Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
020750-2	BETATAKIN	AZ	7210	1948	2004	10.0	9.3	7.8	3.8	0.6	0.0	0.0	0.0	0.0	1.2	6.4	10.0	50.0
021169-2	CAMERON	AZ	4290	1948	1998	2.2	3.8	1.8	1.0	0.0	0.0	0.0	0.0	0.0	0.3	1.3	3.4	10.0
021169-2	CAMERON 1 NNE	AZ	4160	1962	1992	0.6	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.7
021248-2	CANYON DE CHELLY	AZ	5540	1970	2004	1.8	0.9	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.6	5.5
021634-2	CHINLE	AZ	5540	1908	1970	3.4	2.3	1.5	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.9	3.4	10.0
022099-2	COPPER MINE TRADING POS	AZ	6380	1948	1976	1.5	0.8	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.6	6.2
022545-2	DINNEHOTSO	AZ	5020	1950	1974	3.8	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.1	6.7
023102-W	FORT DEFIANCE	AZ	6910	1897	1949	8.7	8.2	3.7	1.4	0.8	0.0	0.0	0.0	0.0	0.1	3.4	6.6	30.0
023303-2	GANADO	AZ	6360	1948	2004	4.7	4.1	3.3	0.7	0.0	0.0	0.0	0.0	0.0	0.4	2.2	5.0	20.0
024438-2	JEDDITO	AZ	6710	1948	1955	10.0	4.7	3.6	0.2	0.2	0.0	0.0	0.0	0.0	0.1	2.4	3.8	30.0
024528-2	KAIBITO	AZ	6000	1950	1961	7.8	3.3	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.9	2.5	20.0
024578-2	KAYENTA	AZ	5680	1915	1978	4.1	2.6	1.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.1	10.0
024686-2	KLAGETOH 12 WNW	AZ	6500	1959	1993	2.7	2.5	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.4	2.3	10.0
024849-2	LEES FERRY	AZ	3140	1916	2004	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	2.1
024872-2	LEUPP	AZ	4700	1948	1981	1.7	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.2	5.1
025129-2	LUKACHUKAI	AZ	6480	1951	2003	3.9	2.7	3.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.8	3.3	20.0
025204-2	MANY FARMS SCHOOL	AZ	5320	1951	1975	0.4	0.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.9	4.4
025665-2	MONUMENT VALLEY	AZ	5560	1980	2004	1.1	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.7	5.1
027440-2	ST MICHAELS 6 WNW	AZ	7640	1906	1927	5.6	5.8	3.1	0.8	0.3	0.0	0.0	0.0	0.0	0.8	2.8	7.3	30.0
027488-2	SANDERS	AZ	5930	1949	2004	2.4	1.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.1	1.4	6.2
027496-2	SANDERS 11 ESE	AZ	6250	1961	1986	6.2	6.2	3.0	1.7	0.4	0.0	0.0	0.0	0.0	0.5	2.6	7.0	30.0
028468-2	TEEC NOS POS	AZ	5180	1962	2004	2.2	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.1	4.8
028792-2	TUBA CITY	AZ	4940	1900	2004	1.5	0.9	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.7	6.2
029410-2	WINDOW ROCK 4 SW	AZ	6900	1937	1999	6.3	6.1	4.7	1.4	0.1	0.0	0.0	0.0	0.0	0.5	2.5	7.8	30.0
291063-1	BLOOMFIELD 3 SE	NM	5810	1914	2004	3.7	2.2	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.6	3.4	10.0
291647-1	CHACO CANYON NATL MON	NM	6140	1922	2004	3.4	2.9	1.7	0.7	0.0	0.0	0.0	0.0	0.0	0.3	1.7	3.6	10.0
292219-1	CROWNPOINT	NM	6990	1914	1969	3.8	5.7	2.2	0.8	0.1	0.0	0.0	0.0	0.0	0.2	1.7	4.4	20.0
293142-1	FARMINGTON AG SCIENCE C	NM	5630	1978	2004	2.5	3.9	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.5	2.7	10.0
293305-1	FORT WINGATE	NM	7000	1940	1966	6.9	4.0	3.5	0.6	0.0	0.0	0.0	0.1	0.0	0.7	1.8	3.7	20.0
293340-1	FRUITLAND 2 E	NM	5150	1914	2003	3.2	2.3	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.2	1.1	2.7	10.0
293420-1	GALLUP 5 E	NM	6600	1918	1979	4.4	2.3	1.6	0.2	0.0	0.0	0.0	0.0	0.0	0.6	1.1	4.5	10.0
295290-1	LYBROOK	NM	7210	1951	2004	6.1	5.2	3.8	1.4	0.0	0.0	0.0	0.0	0.0	0.8	2.1	6.0	30.0
295685-1	MEXICAN SPRINGS	NM	6440	1944	1972	1.9	1.4	2.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.7	9.4
296098-1	NEWCOMB	NM	5570	1948	1971	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4
296465-1	OTIS	NM	6880	1914	2004	6.3	5.6	4.4	1.3	0.5	0.0	0.0	0.0	0.0	0.8	2.8	5.8	30.0
296900-1	PITT RANCH	NM	6460	1948	1968	1.5	3.2	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.6	8.9
298284-1	SHIPROCK	NM	4950	1926	2004	1.4	0.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.0	3.7
298524-1	STAR LAKE	NM	6640	1922	2004	4.9	3.6	2.7	1.1	0.4	0.0	0.0	0.0	0.0	0.5	1.7	3.9	20.0
298830-4	THOREAU 5 ENE	NM	7100	1930	1992	8.3	5.5	5.3	1.1	0.4	0.0	0.0	0.0	0.0	1.4	3.0	8.1	30.0
298919-1	TOHATCHI 1 ESE	NM	6420	1915	1979	3.1	2.4	1.6	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.7	3.9	10.0
298921-1	TOHATCHI 6 NE	NM	5990	1914	1992	2.2	2.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5	2.7	8.6
299031-2	TORREON NAVAJO MISSION	NM	6700	1961	2004	4.9	3.8	2.7	0.9	0.2	0.0	0.0	0.0	0.0	0.7	1.9	4.2	20.0
420157-7	ANETH PLANT	UT	4620	1959	2004	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.2	2.4
420788-7	BLUFF	UT	4320	1928	2004	3.1	1.2	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	3.0	8.2
425582-7	MEXICAN HAT	UT	4250	1948	2004	1.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.3	3.0
425812-7	MONUMENT VALLEY MISSION	UT	5220	1961	1989	3.6	2.5	1.5	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.6	4.2	10.0

TEMPERATURE

In climates that experience freezing temperatures, the amount of surface water run-off expected during winter months increases as percolation through frozen ground is limited. The PRISM Group at Oregon State University developed a spatially gridded average annual minimum temperature and average annual maximum temperature for the climatological period 1971-2000. The PRISM average annual temperature gridded datasets were processed to contours using ESRI's Spatial Analyst software.[1] Polygons were generated and attributed with annual temperature range values as shown in Figure 16. These datasets are provided on the GIS Data DVD (DB/Climate/NN_Temp_Max.shp and DB/Climate/NN_Temp_Min.shp).

[1] Mention of trade names, products, or services does not convey official EPA approval, endorsement, or recommendation.



NAVAJO NATION AVERAGE ANNUAL MINIMUM TEMPERATURE: 1971 - 2000

Source

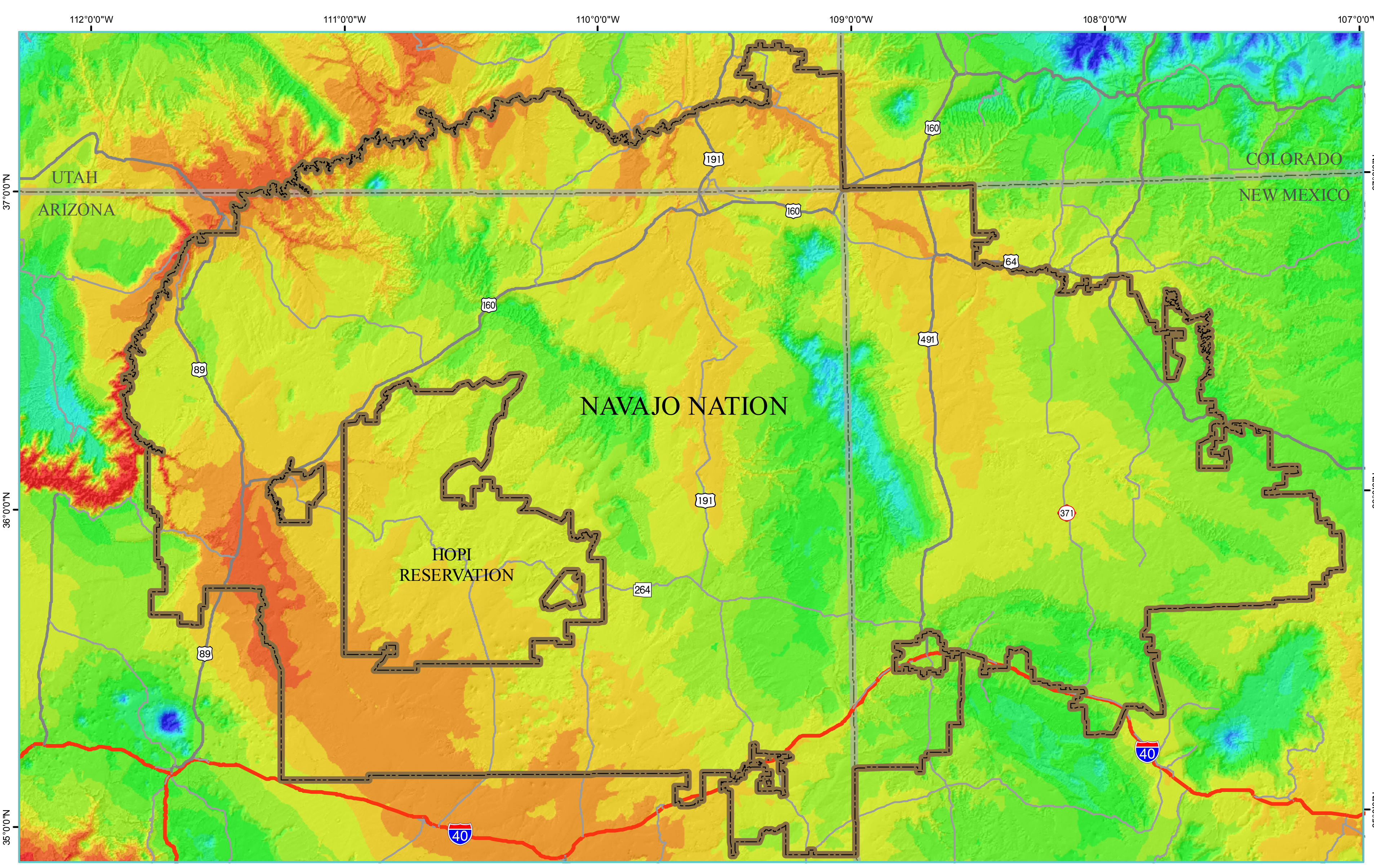
Gridded average daily minimum temperature (30 year average) from PRISM Group at Oregon State University, and contoured by TerraSpectra Geomatics.
Filename: DB/Climate/NN_Temp_Min.shp

0 50 Miles

Map Scale 1:1,900,000

Average Annual Minimum Temperature (°F)

<22	30-32	40-42
22-24	32-34	42-44
24-26	34-36	44-46
26-28	36-38	>46
28-30	38-40	



NAVAJO NATION AVERAGE ANNUAL MAXIMUM TEMPERATURE: 1971 - 2000

Source

Gridded average daily maximum temperature (30 year average) from PRISM Group at Oregon State University, and contoured by TerraSpectra Geomatics.
Filename: DB/Climate/NN_Temp_Max.shp

0 50 Miles

Map Scale 1:1,900,000

Average Annual Maximum Temperature (°F)

<48	56-58	66-68
48-50	58-60	68-70
50-52	60-62	70-72
52-54	62-64	72-74
54-56	64-66	>74

Figure 16. Navajo Nation Average Annual Minimum and Maximum Temperatures: 1971 - 2000.

CLIMATE (continued)

WIND

Wind speeds on the Navajo Nation are usually moderate, although relatively strong winds often accompany frontal activity during late winter and spring months and sometimes occur in advance of thunderstorms. Frontal winds may exceed 30 miles per hour (mph) for several hours and reach peak speeds of more than 50 mph. Spring is generally the windy season. Blowing dust and serious soil erosion of unprotected fields may be a problem during dry periods (DRI, 2003-S08020302; 2003-S08020303; 2007-S05270703).

High Resolution Wind Data

The Department of Energy's Wind Program and the National Renewable Energy Laboratory (NREL) published new wind resource maps for the states of Arizona, Colorado, New Mexico, and Utah. These resource maps show wind speed estimates at 50 meters above the ground and the depict the resource that could be used for utility-scale wind development. Future plans are to provide wind speed estimates at 30 meters, which are useful for identifying small wind turbine opportunities.

As a renewable resource, wind is classified according to wind power classes, which are based on typical wind speeds. These classes range from Class 1 (the lowest) to Class 7 (the highest). In general, at 50 meters, wind power Class 4 or higher can be useful for generating wind power with large turbines. Class 4 and above are considered good resources. Figure 17 indicates that there are areas on the Navajo Nation with wind resources consistent with utility-scale production. This dataset is presented as an indication of potential increased hazard for the air pathway, especially where AUMs are located in higher wind power class areas.

The individual state datasets (Arizona, Colorado, New Mexico, and Utah) were processed into a GIS dataset for the Navajo Nation. The Wind Resources data are provided on the GIS Data DVD (DB/Climate/NN_Wind_Power.shp).

Average Annual Wind Speeds and Average Annual Prevailing Wind Direction

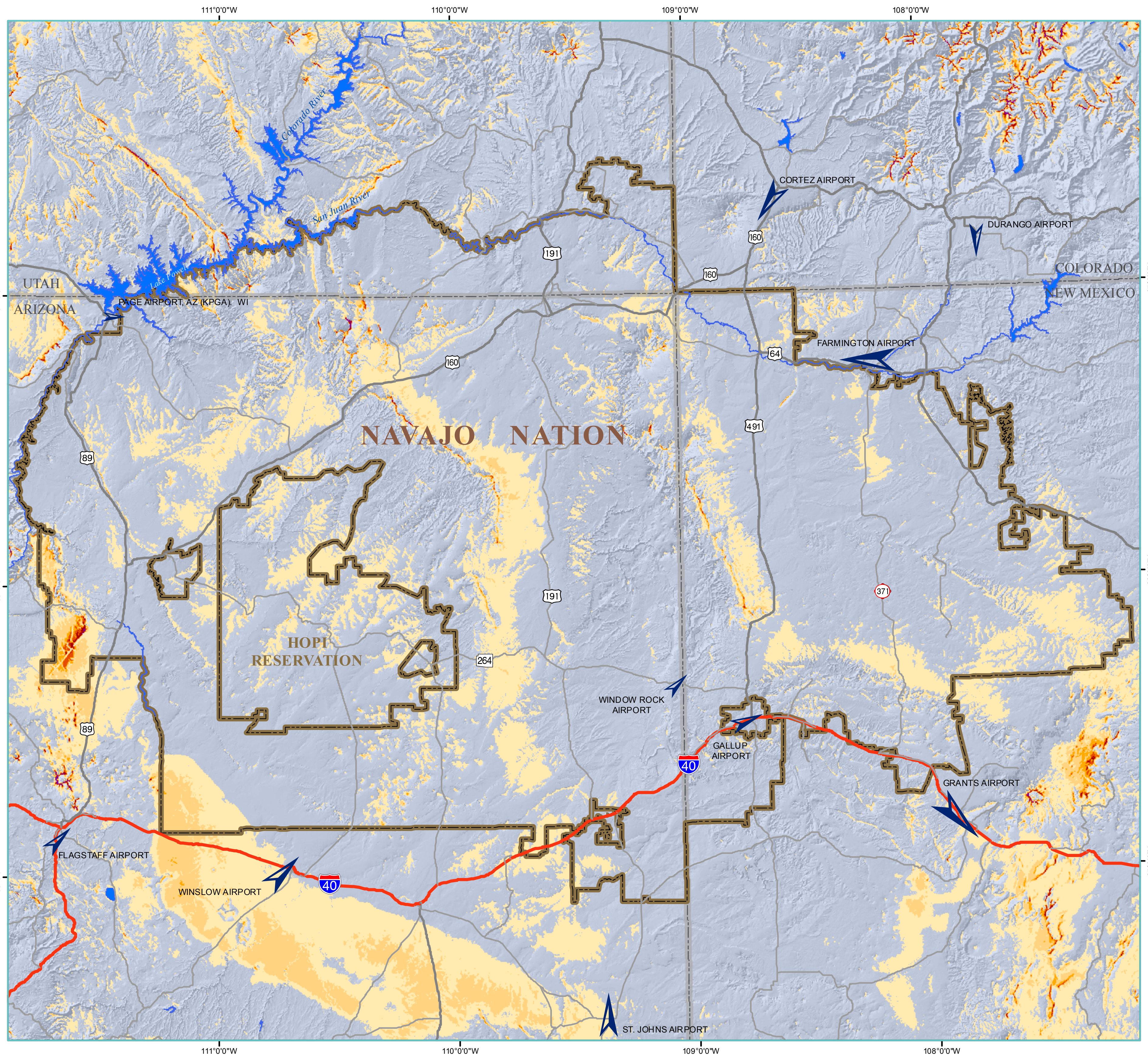
The Western Regional Climate Center (WRCC) is administered by the National Oceanic and Atmospheric Administration and provides monthly average wind speeds. These data are based on hourly observations from all reporting airports in the Western United States, and were collected from 1992-2002. Some stations began operation after 1992. All stations have at least 2 years of hourly data used for the averages. The standard anemometer height for all current stations is 10 meters.

WRCC also provides average annual wind direction. Prevailing wind direction is based on the hourly data from 1992-2002 and is defined as the direction with the highest percent of frequency. Many of these locations have very close secondary maximum which can lead to noticeable differences month to month.

Figure 17 shows the reporting locations, average annual wind speed, and prevailing wind directions for stations located on or near the Navajo Nation. The dataset that is provided on the GIS Data DVD (DB/Climate/NN_Wind.shp) was processed to include only those locations that are located on or proximal to the Navajo Nation. Average monthly wind speed is also tabulated and shown in Table 2. Attribute information in the dataset also provides average wind direction by month and average annual wind direction.

Table 2. Average Wind Speed by Month and Average Annual Wind Speed On and Near the Navajo Nation.

STATION	STATE	ELEV (M)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVERAGE ANNUAL
FLAGSTAFF AP, AZ (KFLG). WI	AZ	2137	5.9	6.5	6.2	7.5	7.3	7.1	5.4	4.3	4.7	5.1	5.7	5.9	6.0
GLENDALE-LUKE AFB, AZ (KLUF)	AZ	332	7.1	7.4	7.7	8.8	8.9	8.8	9.1	8.7	7.7	7.3	7.0	7.0	8.0
GRAND CANYON AP, AZ (KGCN).	AZ	2014	5.8	6.9	6.7	7.8	7.9	7.8	6.0	5.1	5.8	5.6	5.7	5.8	6.4
PAGE AIRPORT, AZ (KPGA). WI	AZ	1304	3.4	4.3	5.3	6.5	6.6	6.7	5.9	5.3	4.9	4.2	3.6	3.1	4.9
PHOENIX SKY HARBOR AP, AZ (K	AZ	337	4.9	5.5	6.0	6.8	6.8	6.6	6.7	6.7	5.9	5.3	4.7	4.4	5.8
PHOENIX-DEER VALLEY AP, AZ (	AZ	450	5.5	6.3	6.9	8.6	8.6	8.7	8.5	8.5	7.7	6.8	6.0	5.4	7.3
PRESCOTT AIRPORT, AZ (KPRC).	AZ	1537	6.9	7.7	8.3	9.3	9.2	9.3	8.2	7.2	7.3	7.1	6.6	6.6	7.8
SCOTTSDALE AP, AZ (KSDL). W	AZ	460	4.0	4.9	5.5	6.6	6.9	6.8	6.9	6.6	6.1	5.0	4.1	3.5	5.5
ST. JOHNS AP, AZ (KSJN). WI	AZ	1747	6.4	8.2	8.7	10.9	10.4	9.7	8.0	6.7	6.9	6.5	6.0	5.5	7.7
WINDOW ROCK AP, AZ (KRQE).	AZ	2055	4.6	5.6	6.6	8.6	8.1	7.3	5.4	4.4	4.8	4.5	4.1	4.1	5.6
WINSLOW AIRPORT, AZ (KINW).	AZ	1488	6.6	7.5	8.4	10.0	10.0	9.7	8.5	7.5	7.3	6.6	6.3	6.0	7.9
CORTEZ AP, CO (KCEZ). WIND	CO	1803	6.0	7.0	8.0	9.0	9.0	9.0	7.0	6.0	7.0	7.0	6.0	6.0	7.0
DURANGO AIRPORT, CO (KDRO).	CO	2038	5.0	6.0	7.0	8.0	8.0	7.0	6.0	6.0	6.0	6.0	5.0	5.0	6.0
MONUMENT PASS, CO (KMNH). WI	CO	3365	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
WOLF CREEK PASS, CO (KCPW).	CO	3243	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
ALBUQUERQUE-DOUBLE EAGLE II	NM	1779	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
ALBUQUERQUE INT'L AP, NM (KA	NM	1620	7.1	8.1	8.8	9.8	9.4	9.0	8.0	7.4	7.2	7.5	7.1	6.9	8.0
FARMINGTON AP, NM (KFMN). W	NM	1677	7.9	8.4	9.1	9.9	9.6	9.3	8.7	7.9	7.8	7.9	7.8	7.0	8.5
GALLUP AIRPORT, NM (KGUP).	NM	1972	5.7	6.7	7.5	9.1	8.7	8.1	6.9	5.9	5.9	5.7	5.3	4.9	6.7
GRANTS AIRPORT, NM (KGNT).	NM	1987	7.7	9.2	9.8	11.0	10.3	9.9	8.0	7.3	7.8	8.6	7.7	7.5	8.7
LOS ALAMOS AP, NM (KLAM). W	NM	2179	3.6	5.0	5.7	6.4	6.5	5.9	5.1	4.2	4.8	4.9	3.9	3.4	5.0
SANTA FE AIRPORT, NM (KSAF).	NM	1934	9.6	10.2	10.7	11.7	11.3	11.0	9.8	9.3	9.4	9.7	9.2	8.7	10.0
BRYCE CANYON AP, UT (KBCE).	UT	2312	8.4	8.9	9.1	10.6	10.0	10.1	8.5	8.5	8.7	8.4	8.2	6.9	8.8
CEDAR CITY AP, UT (KCDC).	UT	1714	7.2	7.6	8.4	9.1	9.4	9.3	8.5	8.2	7.5	6.7	6.5	6.6	7.9



ABANDONED URANIUM MINES AND THE NAVAJO NATION

NAVAJO NATION WIND RESOURCES

0 50 Miles

Map Scale 1:1,750,000

Dust storm near Monument Valley.
Photo taken September 30, 2004 by TerraSpectra Geomatics.

Legend

AVERAGE ANNUAL WIND SPEED (MPH) AND PREVAILING WIND DIRECTION

- 4.9
- 5.0 - 5.9
- 6.0 - 6.9
- 7.0 - 7.9
- 8.0 - 8.9
- 9.0 -10.0

WIND POWER CLASS	RESOURCE POTENTIAL	WIND SPEED AT 50 METERS (MPH)
1	Poor	0.0 - 12.5
2	Marginal	12.5 - 14.3
3	Fair	14.3 - 15.7
4	Good	15.7 - 16.8
5	Excellent	16.8 - 17.9
6	Outstanding	17.9 - 19.7
7	Superb	> 19.7

Source

The wind resource data is from the U.S. Department of Energy's National Renewable Energy Laboratory (NERL).
Filename: DB/Climate/NN_Wind_Power.shp

Average annual wind speed and average annual prevailing wind direction is from the Western Regional Climate Center (WRCC).
Filename: DB/Climate/NN_Wind.shp

Figure 17. Navajo Nation Wind Resources.

ELEVATION AND TOPOGRAPHY

Information about the elevation and topography of a region can provide useful insights into many natural systems, such as the climate, soil development, and vegetation. Much of the Navajo Nation is comprised of plateau-like features 4,000 - 7,000 feet above mean sea level. Rising to elevations of more than 8,000 feet are Navajo Mountain, Defiance Plateau, the Carrizo, Chuska, and Zuni Mountains, and the northern part of Black Mesa. Conversely, the deep canyons of the Colorado River (Grand, Marble, and Glen Canyons), the San Juan Canyon, and the canyon of the Little Colorado River are at elevations of less than 3,000 feet. Generally, the valleys of the Little Colorado, Chaco, and San Juan Rivers and the Chinle Wash range from 4,000 to 5,500 feet in elevation. The highest point on the Navajo Nation is Navajo Mountain in southeastern Utah, at about 10,346 feet and the lowest point is the mouth of the Little Colorado River at about 2,800 feet elevation (Cooley et al., 1969 - S10290201)

Topographic data can be used as an important parameter in evaluating the likelihood of potential hazardous material transport to ground water through infiltration or surface water through runoff. This section discusses Digital Elevation Model data and some of the useful derivative products that can be generated.

DIGITAL ELEVATION MODEL DATA

A Digital Elevation Model (DEM) is a numerical representation of the elevation of terrain. DEM data files contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the surface of the earth. The data typically is stored in a grid format, with pairs of geographic coordinates (x,y) and corresponding elevation values (z). The intervals between each of the grid points will always be referenced to some geographical coordinate system. This is usually either latitude-longitude or UTM (Universal Transverse Mercator) coordinate systems. The closer together the grid points are located, the more detailed the information will be. The details of the peaks and valleys in the terrain will be better modeled with a small grid spacing than when the grid intervals are very large. Spot elevations, other than at the specific grid point locations, are not contained in the file. As a result, summits and valley points that are not coincident with the grid are not be recorded in the file.

The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the USGS effort to provide 1:24,000-scale DEM data for the conterminous United States. NED provides data in a consistent projection (Geographic), resolution (1 arc second or approximately 30 meter), and elevation units (meters). The horizontal datum is NAD83 and the vertical datum is NAVD88.

Some areas of the Navajo Nation have more detailed 1/3 arc second (10 meter) DEM data available, but complete 10 meter coverage is not yet available for the entire Navajo Nation.

A shaded-relief representation of the conterminous United States portion of the National Elevation Dataset (NED). Elevation is portrayed as of range of colors, from dark green for low elevations to white for high elevations (USGS, 1999—S05140301)

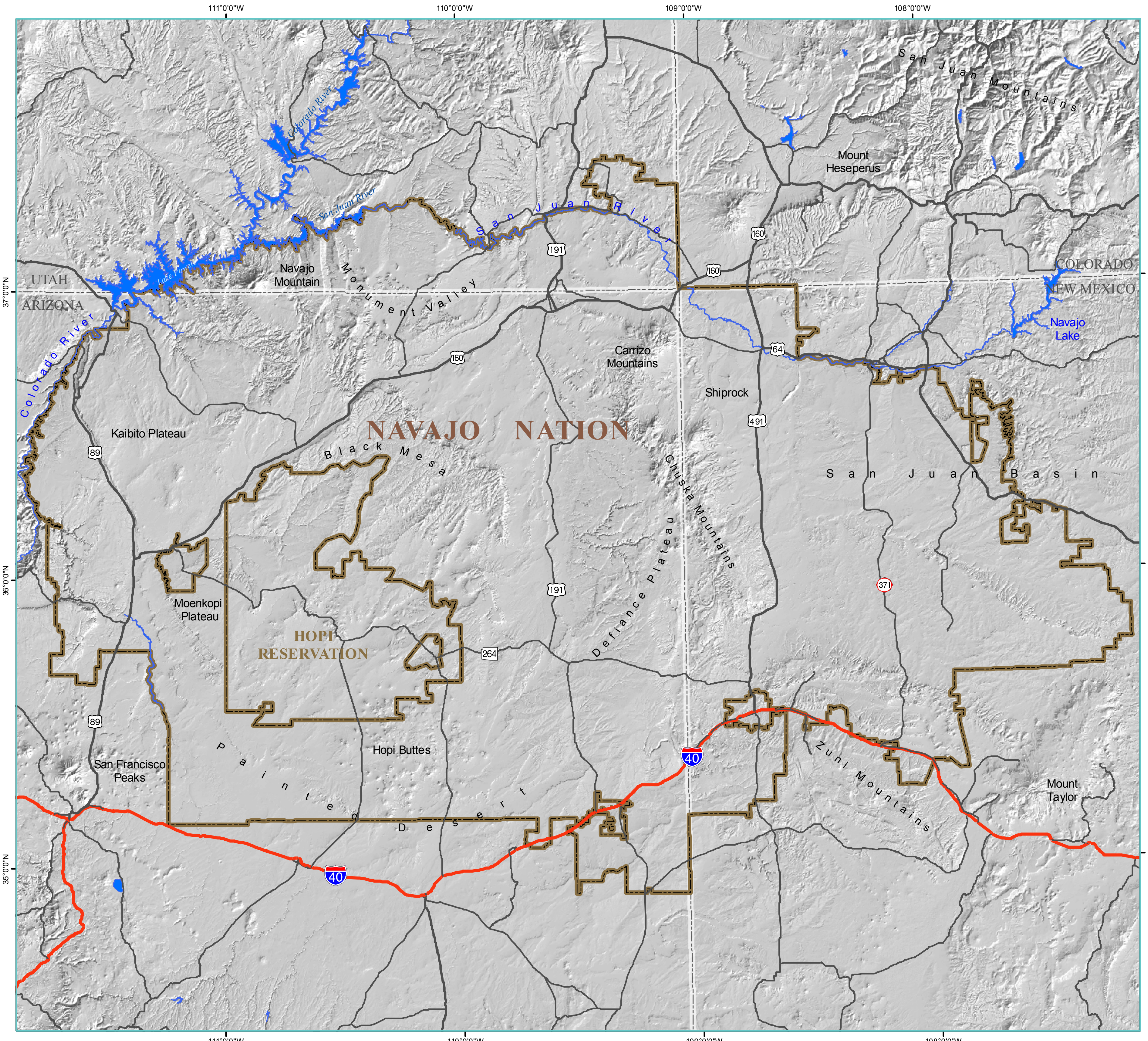
APPLICATIONS OF DEM DATA

A DEM is often an important data layer in a GIS database because elevation data are essential for many earth science applications. Elevation data are critical to many modeling applications such as hydraulic and hydrologic studies, including drainage networks, stream-flow calculations, and watershed delineations. DEMs combined with surface and sub-surface hydrologic data are used for substance transport calculations for environmental hazard analysis. DEMs can be used to create shaded-relief, elevation contours, slope, and aspect maps. The 30 meter resolution DEM for the Navajo Nation is shown as the image in the lower left corner of Figure 18. The DEM has been color-coded to enhance the elevation differences. The DEM raster dataset is provided on the GIS Data DVD (DB/Topo/NN_Elevation.img)

<u>Shaded-Relief Image Maps</u>
There are many practical applications for DEMs. One useful application is to create a shaded-relief map base from DEM data. Relief shading indicates relief by a shadow effect that results in the darkening of one side of terrain features, such as hills and ridges. The darker the shading, the steeper the slope. A shaded relief map helps the user see the topography of an area. The top map on Figure 18 is a shaded relief image of the Navajo Nation that was generated using the NED DEM. Parameters used to create the image were: Solar Azimuth - 125°; Solar Elevation - 45°; Ambient Light - 0.00; DEM scale - 2.0; and Elevation units - meters. Shaded relief maps show features on the surface, such as mountains, valleys, plateaus, and canyons. Areas that are flat or have few features are smooth on the map, whereas areas with steep slopes and mountains appear to have a rough texture. The shaded relief raster dataset is provided on the GIS Data DVD (DB/Topo/NN_Shaded_Relief.img).

<u>Slope</u>
Slope data provides an important parameter for the ground water and surface water pathway assessments. For example, for ground water assessments, the lower the slope the higher the potential for infiltration. Conversely, for surface water pathways, the lower the slope, the lower the potential for runoff. Greater slopes generally result in lower infiltration and higher runoff.

A slope image was generated for the Navajo Nation area using the NED DEM 30-meter DEM data (Figure 19). The DEM data were processed to generate a slope image using percent for the slope value. Areas that have relatively flat terrain are shown as lighter shades of green. As the slope increases, the shades of green darken. These areas correspond with the hilly and mountainous terrain of Navajo Mountain, Black Mesa and the Chuska and Carrizo Mountains. A prominent feature is Shiprock, with very steep, almost vertical slopes on the volcanic neck. The slope raster dataset is provided on the GIS Data DVD (DB/Topo/NN_slope.img).



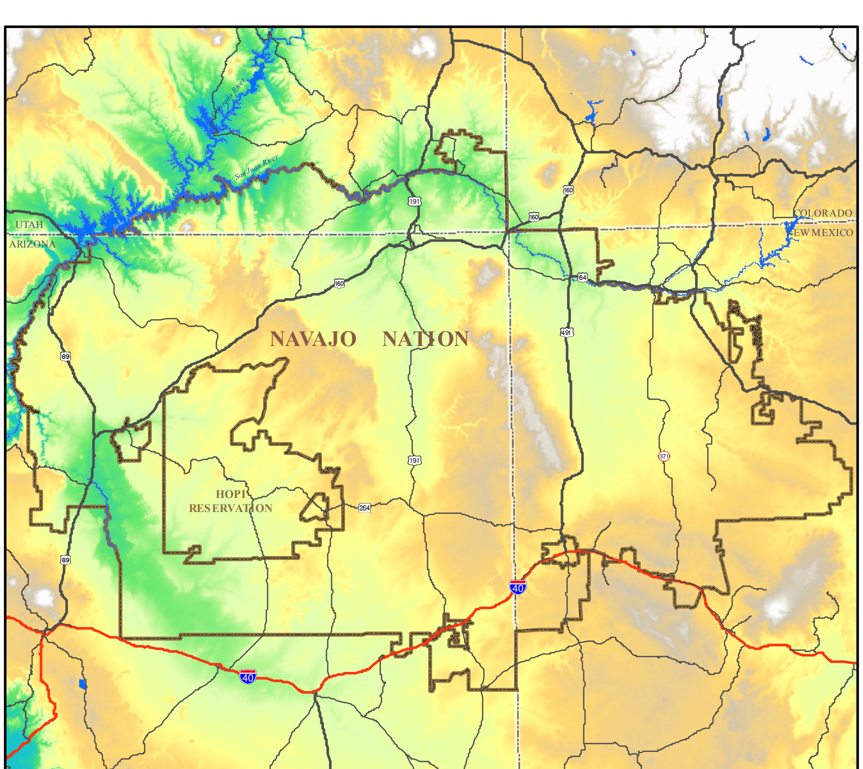
ABANDONED URANIUM MINES AND THE NAVAJO NATION

NAVAJO NATION SHADED RELIEF AND DIGITAL ELEVATION MODEL

N
W E
S

0 50 Miles

Map Scale 1:1,750,000



Color shaded Digital Elevation Model.

Legend

ELEVATION IN METERS

High : 3023.000000

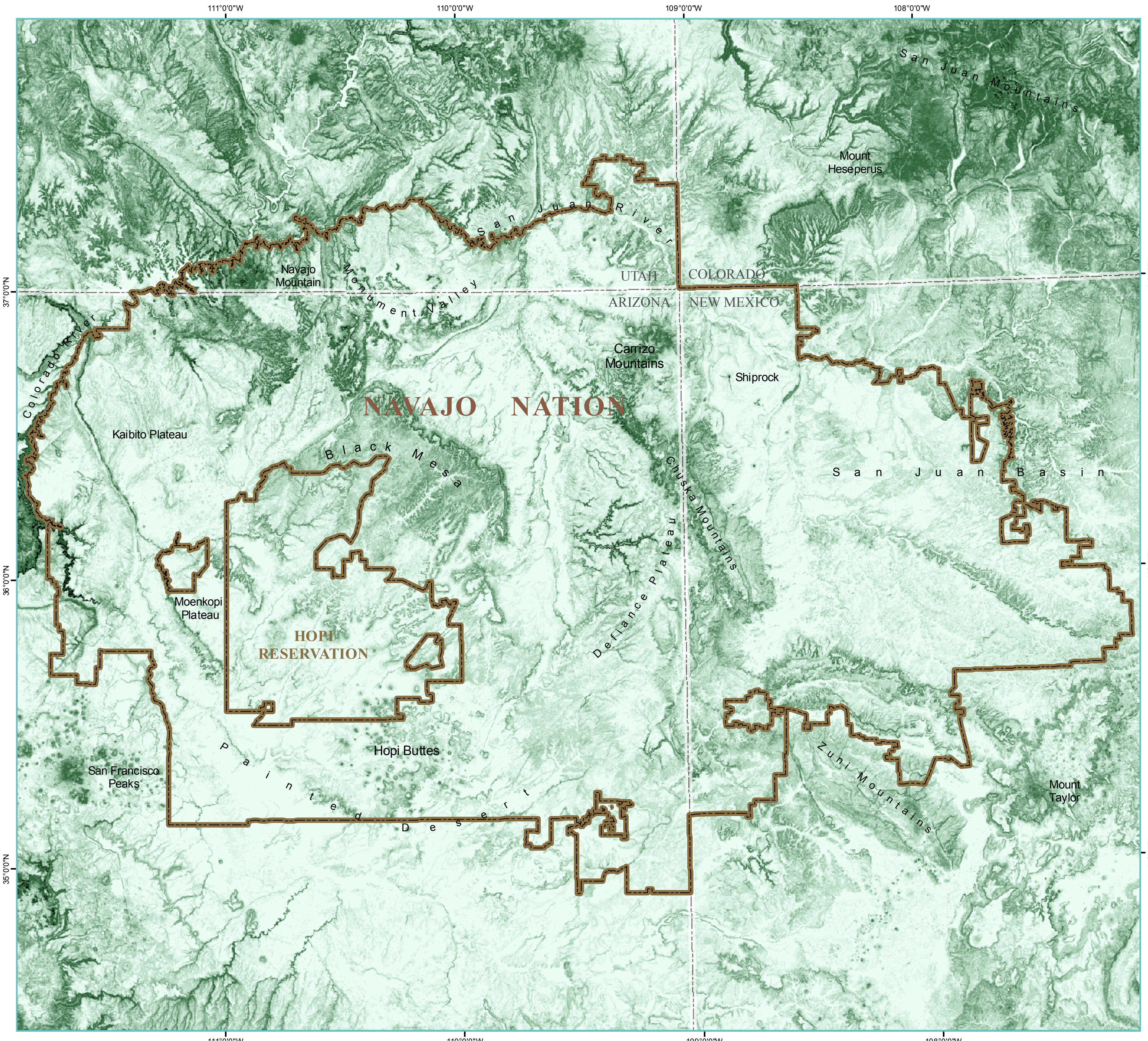
Low : 1128.000000

Source

TerraSpectra Geomatics generated the shaded relief image from U.S. Geological Survey (USGS) National Elevation Dataset (NED) 30 meter resolution Digital Elevation Model (DEM) data.
Filename: DB/Topo/NN_Shaded_Relief.img

TerraSpectra Geomatics generated the color shaded DEM from USGS NED 30-meter resolution DEM data.
Filename: DB/Topo/NN_Elevation.img

Figure 18. Navajo Nation Shaded Relief and Digital Elevation Model.



ABANDONED URANIUM MINES AND THE NAVAJO NATION

SLOPE

N W E S

0 50 Miles

Map Scale 1:1,750,000

Photo taken in the Lukachukai Mountains at an area with steep slope resulting in erosion.

Legend

SLOPE, IN PERCENT

0 - 2	30.1 - 35.0
2.1 - 5.0	35.1 - 40.0
5.1 - 10.0	40.1 - 45.0
10.1 - 15.0	45.1 - 50.0
15.1 - 20.0	50.1 - 75.0
20.1 - 25.0	75.1 - 100.0
25.1 - 30.0	100.1 - 198.0

Source

TerraSpectra Geomatics generated the slope image from U.S. Geological Survey (USGS) National Elevation Dataset (NED) 30 meter resolution Digital Elevation Model (DEM) data.
Filename: DB/Topo/NN_Slope.img

Note: In ERDAS IMAGINE, the relationship between percentage and degree expressions of slope is as follows:

A 45 degree angle is considered a 100% slope
A 90 degree angle is considered a 200% slope

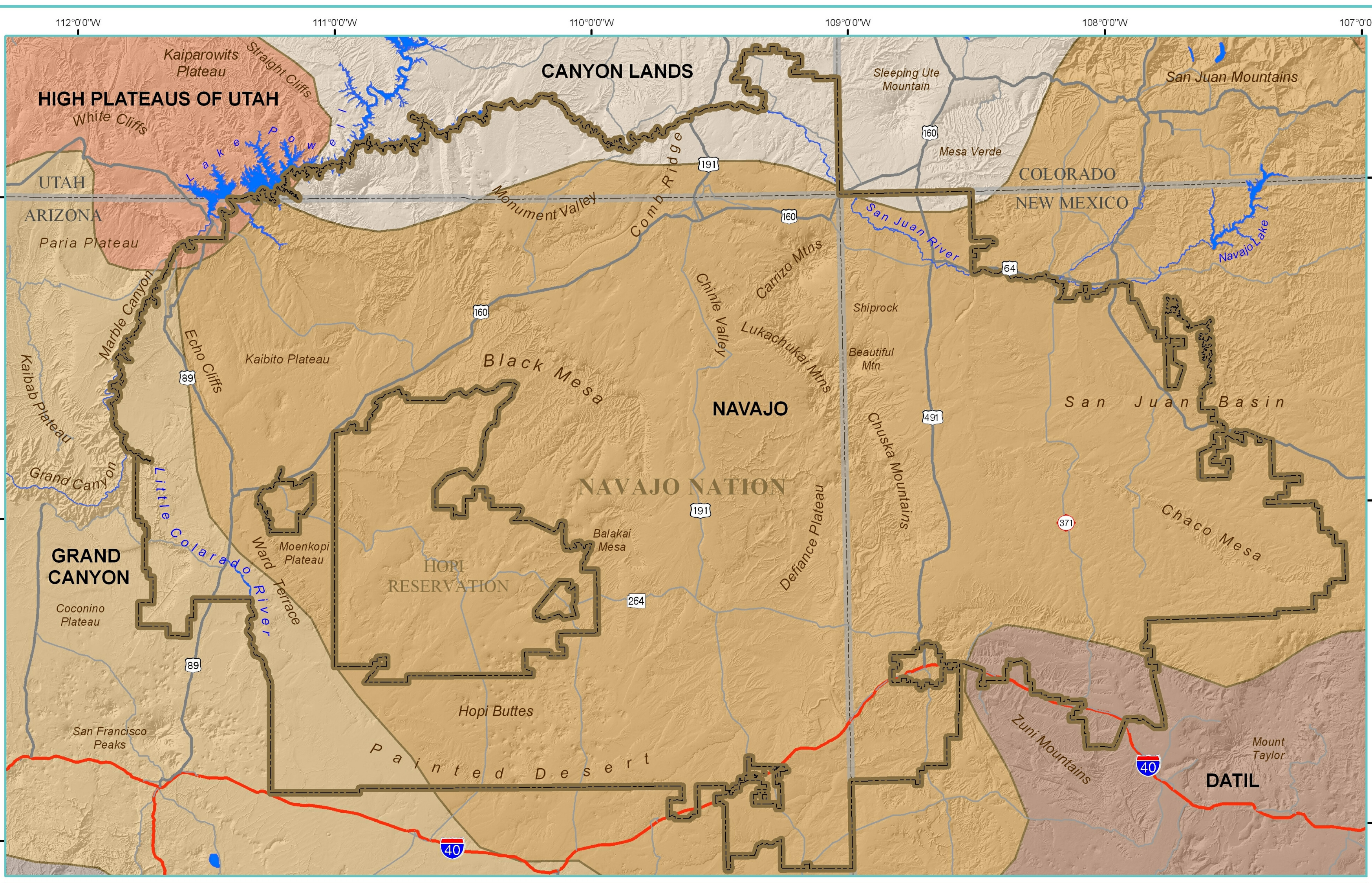
Slopes less than 45 degrees fall within the 1 - 100% range
Slopes between 45 degrees and 90 degrees are expressed as 100 - 200% slopes

Figure 19. Slope (in percent) On the Navajo Nation.

PHYSIOGRAPHY

The word physiography is derived from the Greek word "*Physike*" meaning the science of nature. Physiography is the study of the earth's physical features and the processes that have shaped the landscape. A seminal classification system was developed by Nevin Fenneman in order to help understand and describe regional landscape characteristics. A map resulting from his work was compiled in 1946 for the entire United States at a scale of 1:7,000,000 and titled "Physical Divisions of the United States" (Fenneman, 1946 - S04180301). The United States was divided into eight major divisions, 25 provinces, and 86 sections representing distinctive areas having common topography, rock types and structure, as well as geologic and geomorphic history. The entire Navajo Nation is contained within the Intermontaine Plateaus division and Colorado Plateau province.

The Colorado Plateau province is further separated into physiographic sections on the basis of the distribution of canyons, rock benches, mesas, and plains. Fenneman divided the Colorado Plateau province into the following six sections: Grand Canyon, High Plateaus of Utah (rock terraces of southern Utah), Uinta Basin, Canyon Lands of Utah, Navajo section, and Datil section (Cooley et al., 1969 - S10290201). Figure 20 shows the boundaries of the sections within Fenneman's Colorado Plateau province that cover the Navajo Nation.



PHYSIOGRAPHIC SECTIONS

Source

Physiographic section boundaries are from Fenneman (1946) map titled "Physical Divisions of the United States." Filename: DB/Geology/nn_physio.shp

0 50 Miles

Map Scale 1:1,900,000

Legend

SECTION

- Canyon Lands
- Datil
- Grand Canyon
- Navajo
- High Plateaus of Utah

Figure 20. Physiographic Sections On the Navajo Nation.

The Defiance Plateau, Chuska, Lukachukai, and Carrizo Mountains form the area of the Defiance Uplift that splits the Navajo Nation physiographically and geologically. On the east side is the structurally low San Juan Basin, and on the west side is the structurally low Black Mesa Basin where Black Mesa is at the center. The Zuni Uplift at the location of the Zuni Mountains in New Mexico is another structural uplift at the southeastern margin of the Navajo Nation. The dramatic mesas of Monument Valley are the result of another broad uplift called the Monument Uplift.

These broad gentle upwarps are characteristic of the Colorado Plateau. The southern and eastern flanks of the Monument Upwarp in Arizona and Utah are where the Shinarump hosted uranium deposits are located, while the Defiance Uplift is the location of Morrison hosted uranium in Arizona and New Mexico.

This dataset is provided on the GIS Data DVD (DB/Geology/nn_physio.shp). Attributes include Fenneman division, province, and section codes and names.

GEOLOGY

URANIUM BEARING FORMATIONS ON THE NAVAJO NATION

The Navajo Nation occurs within the Colorado Plateau that is characterized by a relatively complete and continuous sequence of flat-lying Paleozoic and Mesozoic sediments (Figure 22) that are gently deformed by a series of folds and monoclines (Scarborough, 1981 – S09240202). These Mesozoic sediments are the dominant host of uranium and vanadium. Table 3 shows the amount of uranium production by host rock on or within one mile of the Navajo Nation.

Table 3. Uranium Production On or Within One (1) Mile of the Navajo Nation.

URANIUM BEARING HOST ROCKS	Pounds U_3O_8 Produced
Tertiary Bidahochi Formation	580
Cretaceous Dakota Sandstone	458,306
Cretaceous Toreva Formation	55,739
Jurassic Kayenta Formation	547
Jurassic Morrison Formation	98,662,464
Jurassic Navajo Sandstone	229
Jurassic Todilto Limestone	3,116,806
Triassic Chinle Formation	10,033,780
Total Navajo Nation (+ 1 Mile)	**112,328,451**

An understanding of uranium and where it is located on the Navajo Nation requires an understanding of the geology. The original sources of uranium are igneous rocks, but the ore deposits occur in sedimentary rocks. Broad, gentle upwarps are characteristic of the Colorado Plateau, and play a role in the location of uranium mines. The southern and eastern margins of the Monument Uplift in Arizona and Utah are the location of the uranium-mineralized Shinarump Member of the Upper Triassic Chinle Formation. At the center of the uplift the Chinle is eroded away. Likewise, the margins of the northern end of the Defiance Uplift and the northern flank of the Zuni Uplift are the locations of the uranium-mineralized Upper Jurassic Morrison Formation. Cameron, Arizona is the location of another outcropping of the Chinle Formation, where the uranium-mineralized Shinarump and Painted Forest Members are exposed. These rocks, being older, are exposed farther southwest from the very broad Black Mesa Basin. The uranium-mineralized upper sandstone member of the younger upper Cretaceous Toreva Formation is located near the center of the basin.

These areas characterize the southern part of the Colorado Plateau Uranium Province (Finch, 1996 - S05310701). These formations are fluvial or stream and alluvial plain deposited rocks, where more permeable channels of sand formed pathways for uranium-mineralized fluid that were surrounded by less permeable silts and clays. These ores are characterized by tabular sandstone deposits in this region. One likely source of the uranium in these deposits are thick volcanic and related sedimentary beds that overly these host formations. Volcanic arcs that were to the west and south of the province deposited thick fine-grained ash over the host formations. Uranium was later leached from the ash and perhaps precipitated by reduction in the lower host fluvial sandstones (Finch, 1996 - S05310701). However, the source and process of precipitation is still unsettled (McLemore and Chenoweth, 2003 - S08020606). The following is a discussion of the major uranium host sedimentary rocks as well as a brief discussion of the minor host rocks. Also presented are production figures for each of the formations in each of the areas of mineralization across the Navajo Nation.

Triassic Chinle Formation

The Chinle Formation is mineralized in the Cameron, Arizona and the Monument Valley, Arizona and Utah areas (Chenoweth and Malan, 1973 - S10280204). In the Cameron area, the uranium ore deposits are mined mostly from open pits from the fluvial sandstones of the Shinarump and Petrified Forest Members of the Chinle (Chenoweth, 1993 - S10100239). The ore deposits in the Petrified Forest Member were in sandstone lenses up to six feet thick and one mile in length that filled paleostream channels. The Shinarump deposits were similar but smaller. The Petrified Forest Member contained most of the uranium mines and produced about 1,150,000 pounds of uranium oxide; whereas the mines in the Shinarump produced about 55,700 pounds of uranium oxide. In the Bitter Springs area, mines in the Petrified Forest Member produced 718 pounds of uranium oxide.

In the Monument Valley area, uranium was only produced from the Shinarump Member of the Chinle (Gregg and Evensen, 1989-S10020208; and Chenoweth, 1991 - S03100502). In this region the Shinarump forms the many vertical walled mesas of the landscape as erosional remnants of a great fluvial system. Figure 21 shows the uneroded remnant Shinarump paleochannels in red (Young and Malan, 1964 - S06120601). Interpreted locations for eroded Shinarump paleochannels are shown in yellow. The locations of mapped AUMs are shown in black and illustrate the strong correlation with the remnant paleochannels.

The ore deposits occurred in these channels and were up to 200 feet deep and 2,000 feet wide. The ore existed in lenses up to 8 feet thick and a few hundred feet long, with a length to width ratio up to 10 to 1. The Monument No. 2 mine, the largest producer in the region, was found in an inner scour channel that was two miles long, 700 feet wide, and 80 feet deep within an even larger Shinarump paleochannel. In the entire Monument Valley area, about 8.8 million pounds of uranium oxide were produced from the Shinarump Member.

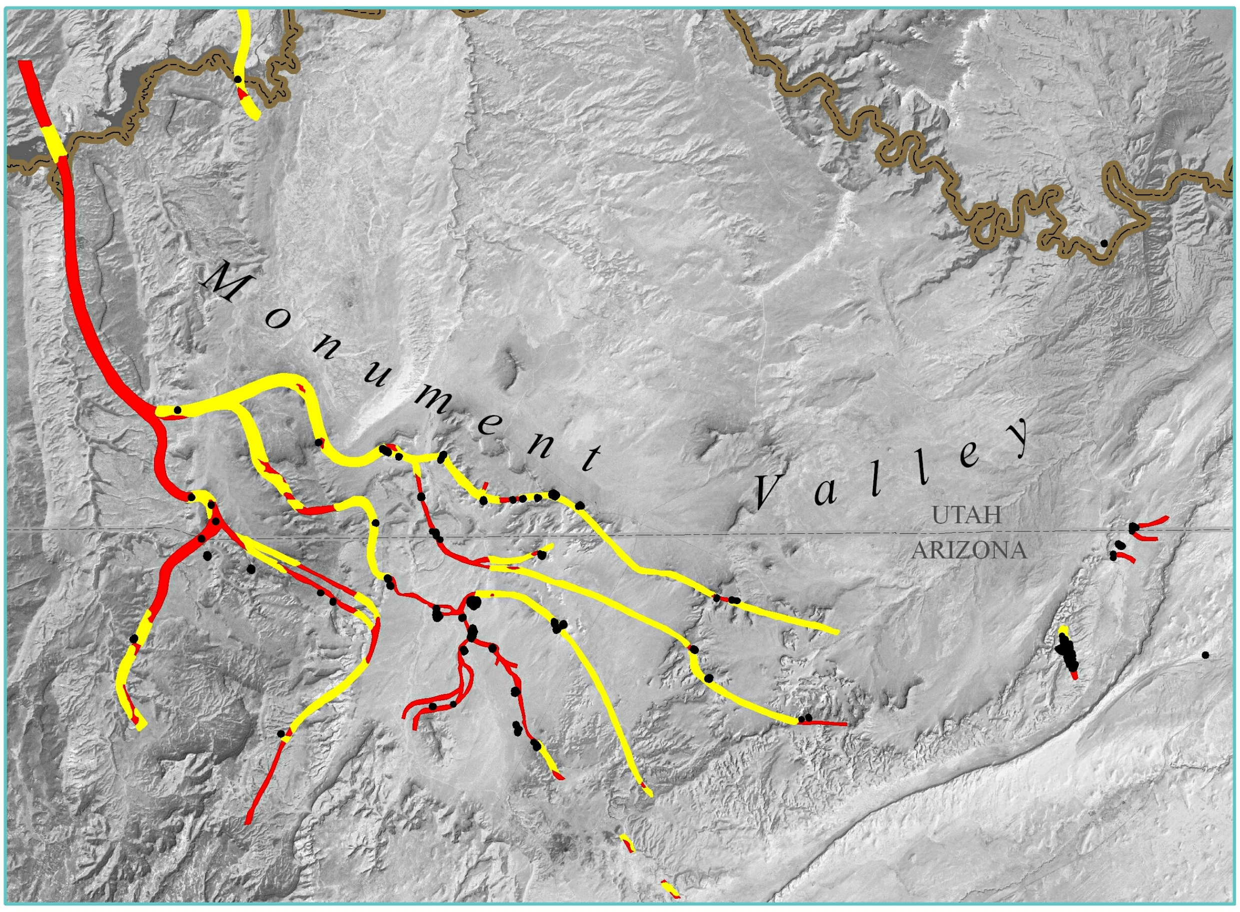
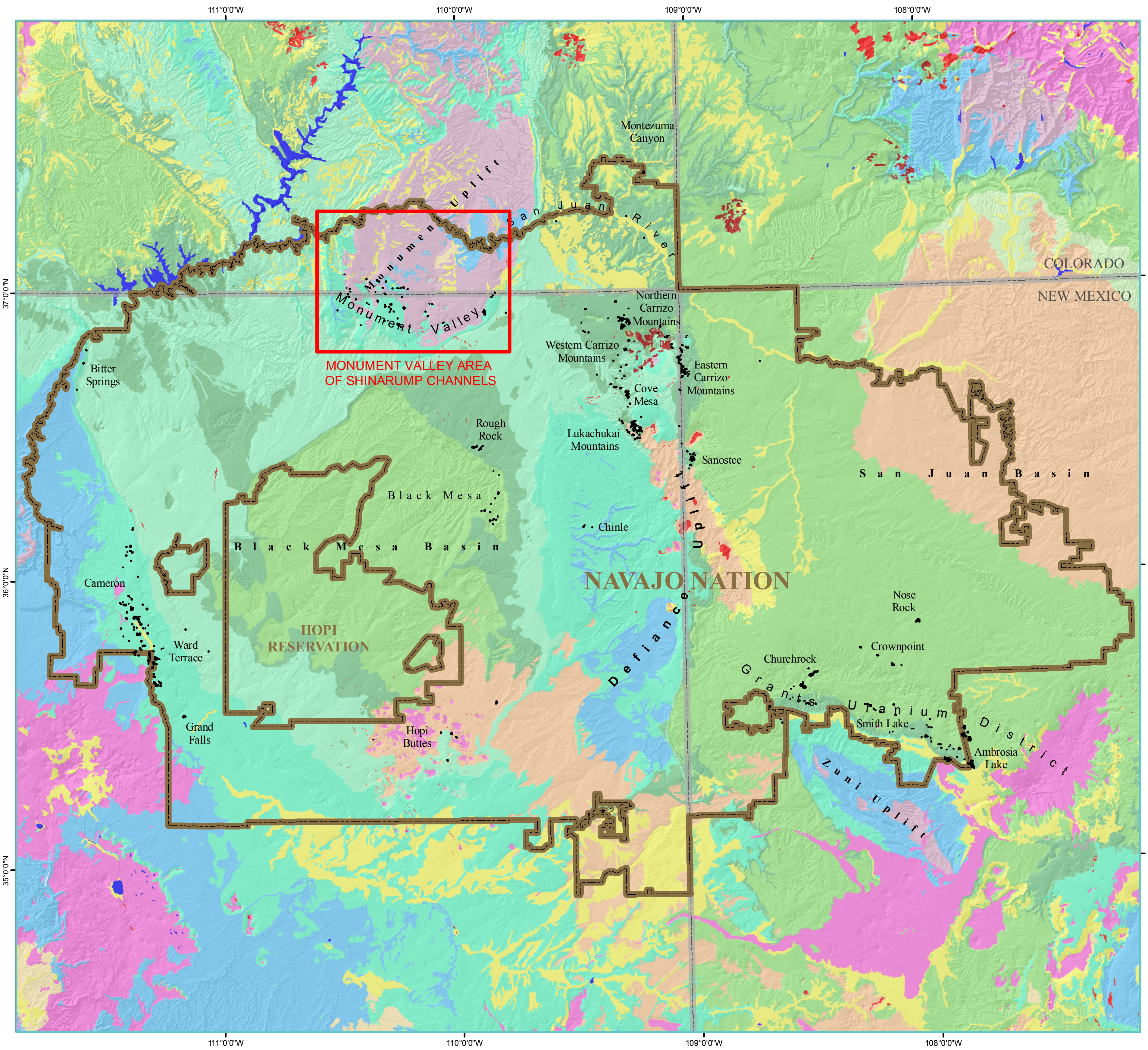


Figure 21. Shinarump Channels in the Monument Valley Area. Uranium-bearing channels of the Shinarump Member of the Triassic Chinle Formation (Young and Malan, 1964 - S06120601). Red represents the uneroded channels and yellow the estimated eroded channels. AUM locations are shown in black.



ABANDONED URANIUM MINES AND THE NAVAJO NATION

GEOLOGY

N W E S

0 50 Miles

Map Scale 1:1,750,000

View to the east across Red Wash from the Red Wash Point Mine site in the the Red Valley Chapter. The cliff on the left is the southern margin of King Tutt Mesa, showing an exposure of the Salt Wash Member of the Morrison Formation. On the right side across Red Wash is a full exposure of the Morrison from the Salt Wash Member in the wash wall to the Brushy Basin Member supporting the linear hill cutting across the photo in the background. Photo courtesy of TerraSpectra Geomatics.

Legend

List of Map Units

SEDIMENTARY ROCKS	IGNEOUS ROCKS
Quaternary	Cenozoic Intrusives
Quaternary-Tertiary	Cenozoic Volcanics
Tertiary	Tertiary-Cretaceous Intrusives
Tertiary-Cretaceous	Cretaceous Volcanics
Cretaceous	PRE-CAMBRIAN ROCKS
Jurassic	Pre-Cambrian Rocks
Jurassic-Triassic	OTHER
Triassic	Water
Paleozoic	Abandoned Uranium Mines

Source

The geologic map is from the RS/GIS Laboratory, College of Natural Resources, Utah State University (2004).

Filename: DB/Geology/NN_Geology.shp

Figure 22. Geologic Map of the Navajo Nation.

GEOLOGY (continued)

Jurassic Todilto Limestone

The Grants Uranium District is one of a few areas in the United States to produce uranium from limestone beds (Chenoweth, 1985 - S08020601). The Jurassic Todilto Limestone is found along the north side of Interstate 40 and below the Morrison rim to the north. It averages about 15 feet thick in this area (Hilpert, 1963 - S08250701). These limestone-hosted ore deposits were mostly mined in open pits. One Todilto Limestone deposit also occurs in the Sanostee area (Chenoweth, 1985 - S08250504).

Jurassic Navajo Sandstone

The Bluestone No. 1 mine, in the eastern part of Monument Valley, is the one known ore deposit on the Navajo Nation that is found in the Navajo Sandstone Formation (Chenoweth, 1991 - S10020202).

Jurassic Morrison Formation

The uranium-mineralized Morrison Formation is found in and around the Carrizo Mountains in Arizona and New Mexico, in the Rough Rock area west of Chinle, Arizona, and in the Sanostee area and along the northern flank of the Zuni Uplift in New Mexico. Chenoweth and Malan (1973 - S10280204) provide an overview of the Morrison Formation in northeastern Arizona, in which they report that the Morrison Formation is comprised of four members in ascending order: the Salt Wash, Recapture, Westwater Canyon, and Brushy Basin. In the Carrizo Mountain and Rough Rock areas it is the Westwater Canyon Member sandstones that are host to the uranium-vanadium ores. It ranges in thickness from 0 to 220 feet thick and is usually at least 180 feet thick where mineralized. Ore bodies are found in paleostream channels within lens shaped ore bodies that range up to 1,100 feet long, up to 400 feet wide and up to 22 feet thick. The ore bodies of the Lukachukai Mountains are the largest and contain less vanadium than other areas. On the northwest, north, and east flanks of the Carrizo Mountains ore bodies occur in clusters, while in the southern Carrizo's they are isolated deposits. In the Rough Rock area, ore bodies are few and small. In the Sanostee area the Salt Wash Member deposits are few and very small, whereas the Recapture Member is the largest producer (Chenoweth, 1985 - S08250504). The Enos Johnson 3 was the largest producing mine (134,438 pounds of uranium) in the Recapture and was the only mine outside the Grants Uranium District that produced during the post-AEC period (after 1970). The Morrison produced about 4.7 million pounds of uranium in Arizona and in the East Carrizo's and Sanostee areas of New Mexico.

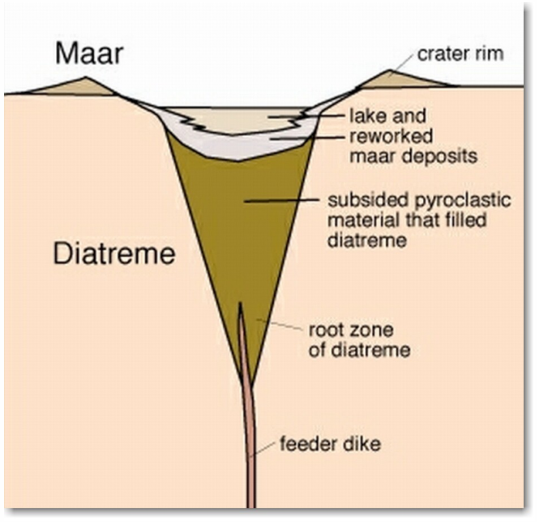
The Morrison in the Grants Uranium District dips gently northward from the Zuni Uplift into the San Juan Basin to the north, such that Morrison ore deposits are found at the surface along the rim north of Interstate 40 and at increasing depths northward (Hilpert, 1963 - S08250701). In this region, the Salt Wash Member is absent, leaving only the Recapture, Westwater Canyon, and Brushy Basin Members. Thickness ranges from 0 to 600 feet thick, averaging 450 feet. The Poison Canyon Mine, which was an economic producer, is a sandstone bed that is an intertongue of the Westwater Canyon within the Brushy Basin. The Westwater Canyon Member contains the largest number and size of ore deposits. In total, all members of the Morrison in this region produced about 94 million pounds of uranium.

Jurassic Kayenta Formation, Cretaceous Dakota Sandstone, Cretaceous Toreva Formation, and Tertiary Bidahochi Formation

Only two ore deposits (Hosteen Nez and Yellow Jeep No. 7A and 7B) are found in the Jurassic Kayenta Formation in the Ward Terrace area near Cameron, Arizona (Chenoweth, 1993 - S10100239). Several ore deposits are found in the 70 to 180 foot thick Cretaceous Dakota Sandstone in the Church Rock area. The Church Rock Mine is the most notable deposit as it is the only one to have produced from the Morrison and the Dakota (188,686 pounds of uranium).

Uranium ore deposits are found in the fluvial upper member of the Cretaceous Toreva Formation on the eastern side of Black Mesa (Chenoweth, 1990 - S10100236).

The Tertiary Bidahochi Formation is host to one productive uranium mine, the Morale Mine, found in the Hopi Buttes area of the Southern AUM Region. It is found in lake deposits of a volcanic crater (maar), likely above a buried volcanic neck (diatreme). Hopi Buttes is the largest such area in the world, containing more than 300 diatremes (Chenoweth, 1990 - S10020205)



Model of a Maar - Diatreme Volcano. Maars are low-relief volcanic craters formed by shallow phreatic explosions. The diatremes are subsurface pipes that fed the maars and were filled by volcanic material at the time of the eruption. They are now exposed because of lowering of the land surface by erosion. *From http://volcano.und.nodak.edu/vwdocs/*

GEOLOGIC MAPPING ON THE NAVAJO NATION

The geologic map (Figure 22) was produced from four state geologic maps for the Southwest Regional Gap Analysis Project. These maps were compiled at a map scale that is appropriate for regional applications. This geologic dataset is provided on the GIS Data DVD (DB/Geology/NN_Geology.shp)

In 1969, USGS published a Geological Survey Professional Paper 521-A that included a "Geologic Map of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah" at a scale of 1:125,000 (Cooley et al., 1969 - S10290201). Small portions of the map have been automated (e.g., Red Valley and Cove Chapters), but the entire map is not available in digital format. The USGS Navajo Nation Studies Program in Flagstaff, Arizona has begun a new geologic mapping project to remap the Navajo Nation. The Cameron, Arizona quadrangle is the first in a series of 30 x 60 minute quadrangles (1:100,000 scale) to be mapped, and is in a review draft stage. These maps will be made available by the USGS in GIS format.

GEOLOGY (continued)

KARST

Karst is a term used to describe a topography characterized by caves, sinkholes, and underground drainage. What distinguishes a karst landscape from other landscapes is the dominance of solution features in soluble sedimentary rocks, such as limestone and gypsum (Hill, 2003 - S06150302).

An important parameter in the evaluation of potential ground water pathways is whether an AUM site is located in an area of karst terrain. In karst formations, ground water moves rapidly through solution channels caused by dissolution of the rock materials. Therefore, hazardous substances associated with an AUM located in karst terrain would be more likely to reach the ground water (EPA, 1991 - S01230301).

Figure 23 shows areas of karst on and near the Navajo Nation. These data are from a digital version of the U.S. Geological Survey Open File Report 2004-1352, "Engineering Aspects of Karst." The open-file report is a map with accompanying explanatory text. The map shows areas containing distinctive surficial and subterranean features that have been developed by solution of carbonate and other rocks and are characterized by closed depressions, sinking streams, and cavern openings. These areas are commonly referred to as karst. Included on the map are areas of features analogous to karst, also called pseudokarst, which is karst-like terrain produced by processes other than the dissolution of rocks.

According to this regional karst dataset, there are some areas of karst carbonate rocks on the western and southernmost edges of the Western AUM Region, on the north central edge of the North Central AUM Region, and on the southern edge of the Eastern AUM Region. Volcanic pseudokarst also is present in the southernmost area of the Western AUM Region. Unconsolidated pseudokarst is shown extending north from the south central edge of the Northern AUM Region. This is the only area on the Navajo Nation that appears to have AUMs within karst or karst-like terrain.

This dataset is provided on the GIS Data DVD (DB/Geology/NN_Karst.shp). These data are intended for geographic display and analysis at the national level, and for large regional areas. The data should be displayed and analyzed at scales appropriate for 1:7,500,000-scale data. These map layers are intended to provide users with a national scale karst data coverage to use for graphic and demonstration purposes. These data are not intended for, and should not be used for, site-specific research.

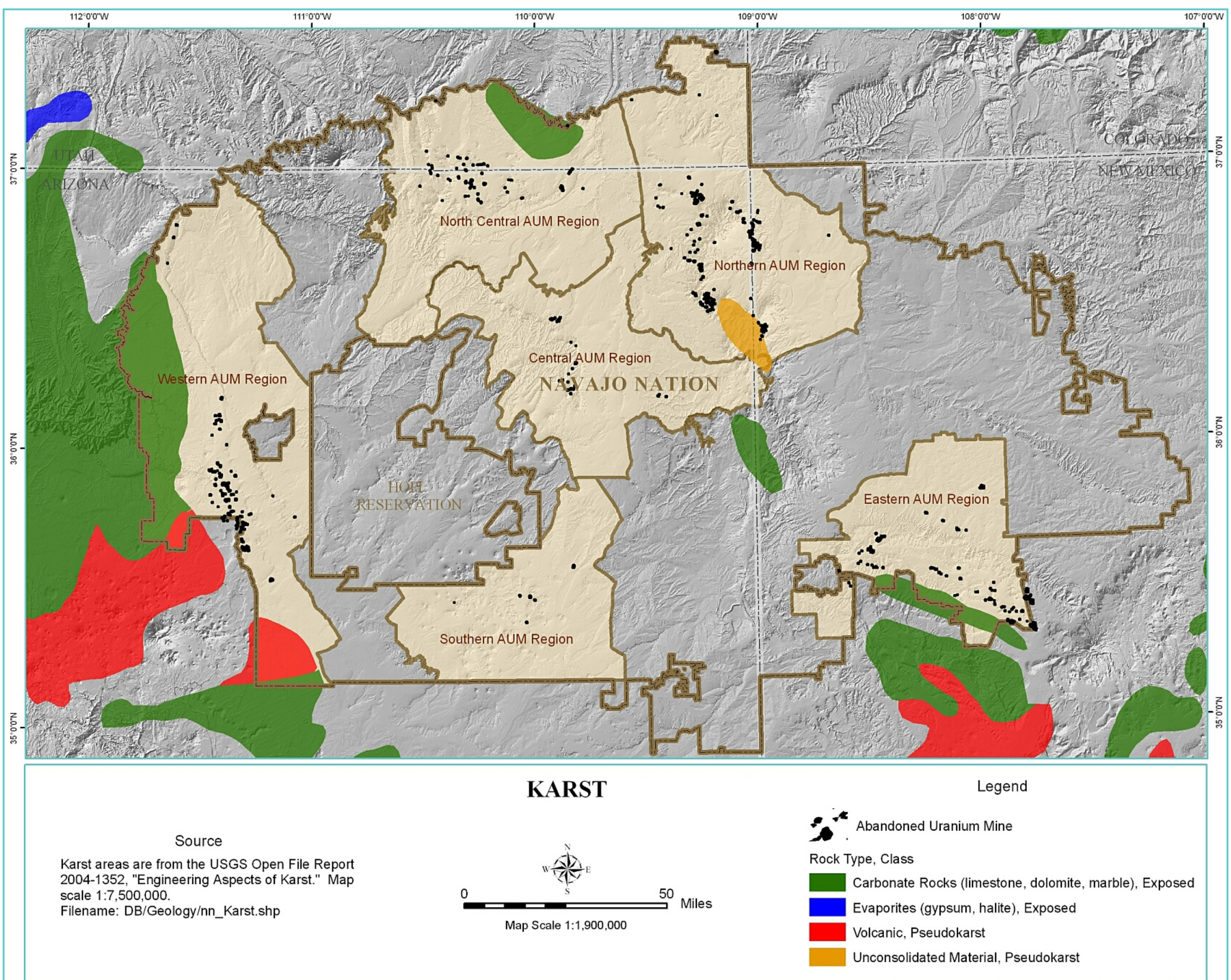


Figure 23. Karst Terrain On and Near the Navajo Nation.

GROUND WATER RESOURCES

Ground water is a potential pathway for the transport of hazardous substances. The ground water pathway is important when assessing the threat posed to drinking water and to populations relying on ground water as their source of drinking water. Evaluation of the ground water pathway requires a general understanding of the local geology and subsurface conditions. Of particular interest is descriptive information relating to the subsurface stratigraphy, permeability of the underlying strata, aquifers, and ground water use. There are two additional key considerations in the evaluation of ground water pathways: depth to aquifer and the presence of karst terrain.

COLORADO PLATEAU REGIONAL AQUIFERS

The Navajo Nation falls within the Colorado Plateau and Wyoming basin (referred to hereafter as Colorado Plateau) consolidated rock aquifer system, which covers northern Arizona, western Colorado, northwestern New Mexico, and eastern Utah (Figure 24). This area is approximately coincident with the Colorado Plateau physiographic province. The distribution of aquifers in the Colorado Plateau is controlled in part by the structural deformation and erosion that has occurred since deposition of the sediments that compose the aquifers. The principal aquifers in younger rocks are present only in basins, such as the San Juan basin. In uplifted areas, such as the Defiance Uplift, younger rocks have been eroded away, and aquifers are present in older rocks that underline more extensive parts of the Colorado Plateau area (Robson and Banta, 1995 - S06150301).

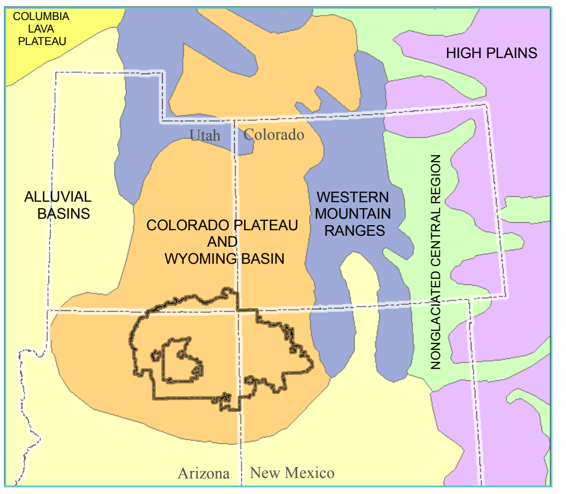


Figure 24. Ground Water Regions (from Robson and Banta, 1995 - S06150301).

For municipal water on the Navajo Nation there are several aquifers: Coconino (C), Navajo (N), Dakota (D), Morrison (M), Mesaverde, and numerous alluvial aquifers. The three primary water-bearing aquifers for the Navajo Nation are the D-, N-, and C-aquifers (Navajo Department of Water Resources [NDWR], 2000 - S12130214). Figure 25 shows the areas of aquifer recharge on the Navajo Nation and Figure 26 depicts water level contours and general direction of water movement on the Navajo Nation. These datasets are provided on the GIS Data DVD (DB/Water/NN_Aquifers.shp and NN_Water_Level_and_Direction.shp)

<u>D-Aquifer:</u> The Dakota, Cow Springs, Westwater Canyon Member of the Morrison Formation, and Entrada Sandstones form the D-multiple aquifer system. Recharge to the D-aquifer is from local precipitation and runoff from the Defiance Uplift to the east. Ground water flows to the west, and south from the areas of recharge (Figure 26). Some water is lost from the aquifer by downward leakage into the underlying aquifer. Water in the D-aquifer is of marginal to unsuitable chemical quality for domestic use (Arizona Department of Water Resources [ADWR], 2003 - S08030302).

<u>N-Aquifer:</u> The Navajo Sandstone and Wingate Sandstone are the main water-bearing units in the N-aquifer. The aquifer generally is under water-table conditions (unconfined). Precipitation falling on the exposed aquifer units is the main source of recharge for the N-aquifer. Groundwater in the N-aquifer moves southward and southeastward under Black Mesa. The flow divides under the mesa, moving westward and eastward. Water in the N-aquifer is of good quality and suitable for most uses (Cooley et al., 1969; ADWR, 2003; and NDWR, 2000).

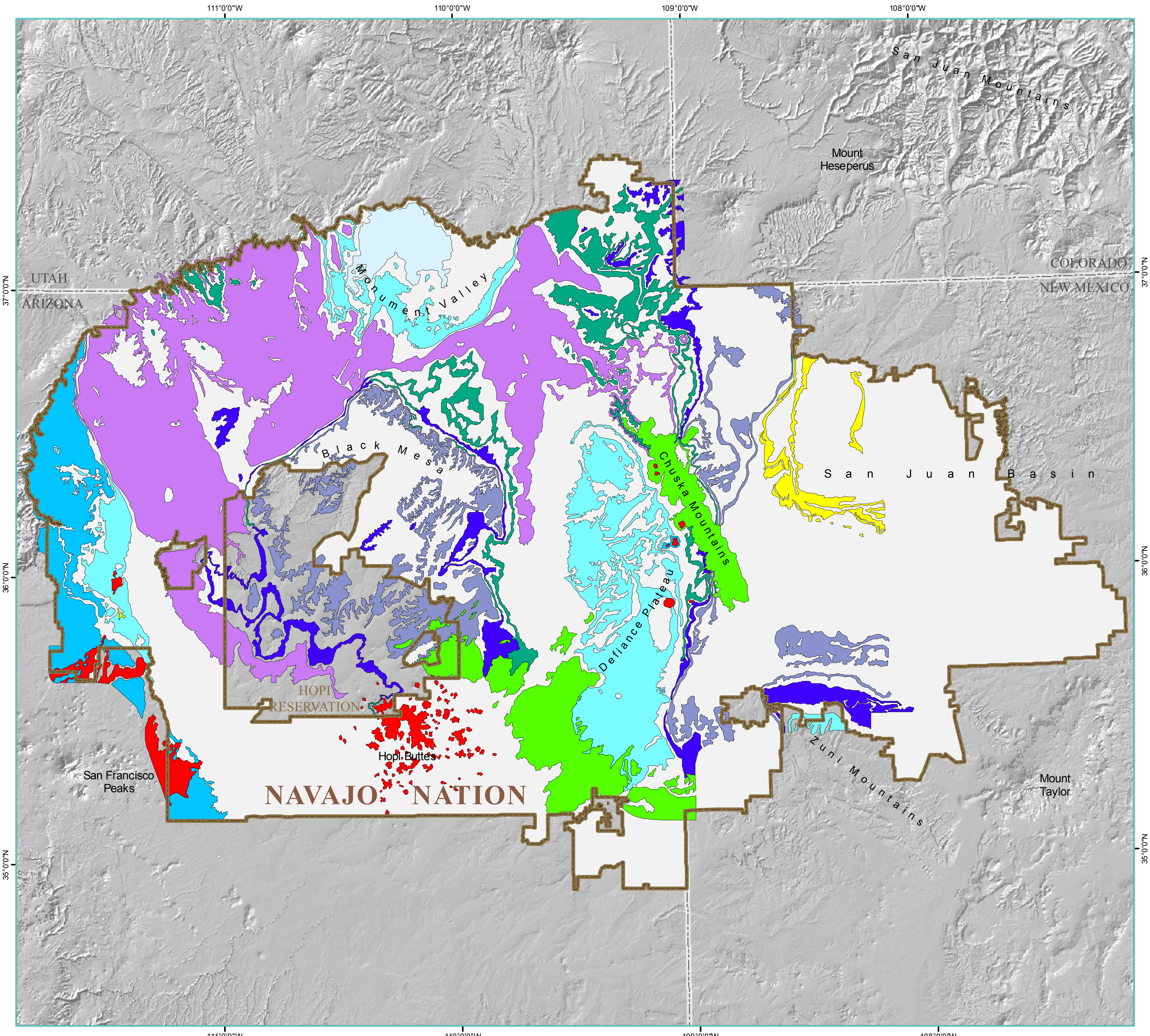
<u>C-Aquifer:</u> The Coconino Sandstone and its lateral equivalents, the De Chelly and Glorieta Sandstones, are the chief water-bearing units in the southern part of the Colorado Plateau. These units are interconnected hydraulically, and with the upper part of the Supai Formation, the Yeso Formation, and the San Andres Limestone, form the C-aquifer system (Cooley et al., 1969; NDWR, 2000). The C-aquifer is recharged by rainfall and by runoff from the Defiance Uplift. Ground water in the C-aquifer moves to the northwest from the large areas of inflow on the south and east (Cooley et al., 1969; ADWR, 2003, NDWR, 2000).

<u>Local Aquifers:</u> Water-yielding units excluded from the principal aquifers can form aquifers of local importance, but these units either are not extensive enough or are not productive enough to be considered as principal aquifers. In general, these rocks are considered to be confining units containing minor water-yielding units (Robson and Banta, 1995). Local aquifers are of importance for domestic water supplies where the three regional aquifers, the D-, N-, and C-aquifers are too deep or have unsuitable water quality (ADWR, 2003). Unconsolidated sediments and alluvial deposits, mainly of Quaternary age, have hydrologic importance (Cooley et al., 1969). The local aquifers include alluvial deposits, which occur in washes and stream channels throughout the basin and various sandstones. Water enters the alluvium as discharge from the D-, N- and C-aquifers, as streamflow infiltration, or as direct rainfall. In thicker sections the alluvium is a steady source of water, but smaller washes can go dry because of overuse or drought conditions (ADWR, 2003). The Quaternary deposits mostly are less than 30 feet thick, but are as thick as 225 feet in a few places. They form a discontinuous, rather permeable mantle. The alluvium is the chief source of water in dug wells; it is also the source of water in some springs and drilled wells. Depth to water in wells drilled in the alluvium is shallow, from a few feet to about 100 feet below the land surface (Cooley et al., 1969).

WATER SOURCES

Identifying the location of drinking water wells, the depth of the aquifer for the well, and if possible, the populations associated with a drinking water well are especially important information for contaminant pathway assessments. Depth to shallowest aquifer is an important measurement when evaluating potential contamination of ground water. An aquifer is defined by the EPA as a “saturated subsurface zone from which drinking water is drawn.” The shallower a source of water, the higher the threat of contamination by hazardous substances (EPA, 1991 - S01230301).

The NDWR Water Management Branch maintains an extensive database of ground water well information, which is the primary data resource for ground water information on the Navajo Nation. For this NAUM Project, the NDWR wells dataset was augmented with data from the ADWR, New Mexico Office of the State Engineer, Utah Division of Water Rights, USACE water sample locations, USGS NHD, Geographic Names Information System, USGS Ground Water Site Investigations Database, DRGs, DOQQs, and the Church Rock Uranium Monitoring Project (CRUMP) sampled water sources. The database includes available information for: Well Identifiers (NDWR, alias names, PWSID, and USGS-ID), source of the well location, operator, type of well (artesian, mineral, observation, water or well; developed or natural spring; and unknown), use (agriculture, domestic, industry, livestock, municipal, other and unknown), well depth, and aquifer. Wells within four miles of an AUM were used as a target parameter in the HRS-derived model. Figure 27 shows the locations of water sources (symbolized by well type) within four miles of an AUM. The inset map provides an enlarged view to show better detail of the well type data and symbols. All well types were included in the analysis (only oil wells and possible oil wells were excluded). Wells outside the four mile buffers are also shown with a single point symbol. These datasets are provided on the GIS Data DVD (DB/Water/NN_Wells.shp and NN_Wells_4mi.shp).



ABANDONED URANIUM MINES AND THE NAVAJO NATION

AREAS OF AQUIFER RECHARGE ON THE NAVAJO NATION

N W E S

0 50 Miles

Map Scale 1:1,750,000

Legend

RECHARGE UNIT DESCRIPTION

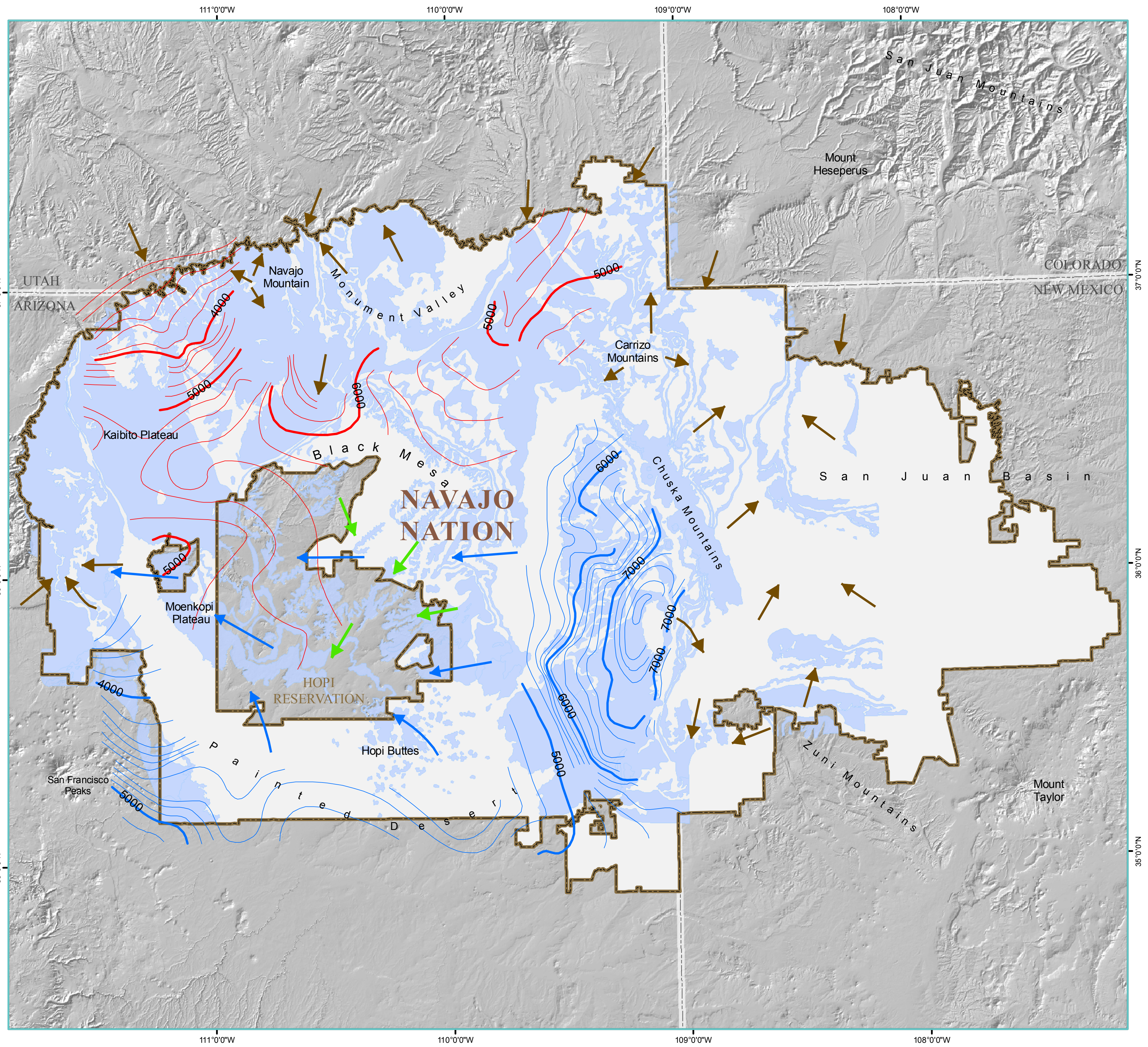
- Rocks receiving little or no recharge.
- Cedar Mesa Sandstone Member of the Cutler Formation
- Shinarump Member of the Chinle Formation, Moenkopi Formation and De Chelly Sandstone Member of the Cutler Formation in Monument Valley; Sonsela Sandstone Bed of the Petrified Foest Member and Shinarump Member of the Chinle Formation, Moenkopi Formation, and De Chelly Sandstone on the Defiance Plateau; Shinarump Member and Sonsela Sandstone Bed of the Petrified Forest Member of the Chinle Formation in the Zuni Mountains; Shinarump Member in the western part of the Navajo Nation.
- Chuska Sandstone and upper member of the Bidahochi Formation
- Rocks of the D multiple-aquifer system. Dakota Sandstone, Cow Springs Sandstone and Westwater Canyon Member of the Morrison Formation; and the Entrada Sandstone in the southern and central parts of the Navajo Nation.
- Kaibab Limestone, Toroweap Formation, and Coconino Sandstone
- Mesaverde Group. Toreva Formation and Yale Point Sandstone in Black Mesa; Gallup Sandstone and Point Lookout Sandstone in San Juan Basin.
- Salt Wash and Westwater Canyon Members of the Morrison Formation, Summerville Formation, and Bluff Sandstone in the northeastern part of the Navajo Nation; Salt Wash Member of the Morrison Formation, Summerville Formation, Bluff Sandstone, and Entrada Sandstone in the northwestern and central parts of the Navajo Nation.
- Rocks of the N multiple-aquifer system. Navajo Sandstone, sandy facies of the Kayenta Formation, and Lukachukai member of the Wingate Sandstone.
- Ojo Alamo Sandstone, Pictured Cliffs Sandstone, and Cliff House Sandstone
- Volcanic Rocks

Source

Areas of recharge and discharge of aquifers on the Navajo Nation is from Plate 5 "Map Showing Water-Level Contours, Direction of Water Movement, and Areas of Recharge and Discharge of Aquifers in the Navajo and Hopi Indian Reservations" in U.S. Geological Survey Professional Paper 521-A "Regional Hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah", by M.E. Cooley and others, 1969.

Filename: DB/Water/NN_Aquifers.shp

Figure 25. Areas of Aquifer Recharge On the Navajo Nation.



ABANDONED URANIUM MINES AND THE NAVAJO NATION

WATER LEVEL CONTOURS, DIRECTION OF WATER MOVEMENT, AND AREAS OF RECHARGE OF AQUIFERS ON THE NAVAJO NATION

0 50 Miles

Map Scale 1:1,750,000

Source

Water level contours, direction of water movement, and areas of recharge of aquifers on the Navajo Nation are from Plate 5 "Map Showing Water-Level Contours, Direction of Water Movement, and Areas of Recharge and Discharge of Aquifers in the Navajo and Hopi Indian Reservations" in U.S. Geological Survey Professional Paper 521-A "Regional Hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah", by M.E. Cooley and others, 1969.

Filenames:
DB/Water/ NN_Water_Level_and_Direction.shp
DB/Water/NN_Aquifers.shp

Legend

WATER LEVEL CONTOURS

7000 C Aquifer Water-level Contour (contour interval 100 and 200 feet)

4000 N Aquifer Water-level Contour (contour interval 200 feet)

DIRECTION OF WATER MOVEMENT

C Aquifer Direction of Ground Water Movement

Near Surface Direction of Ground Water Movement; Near Surface Direction

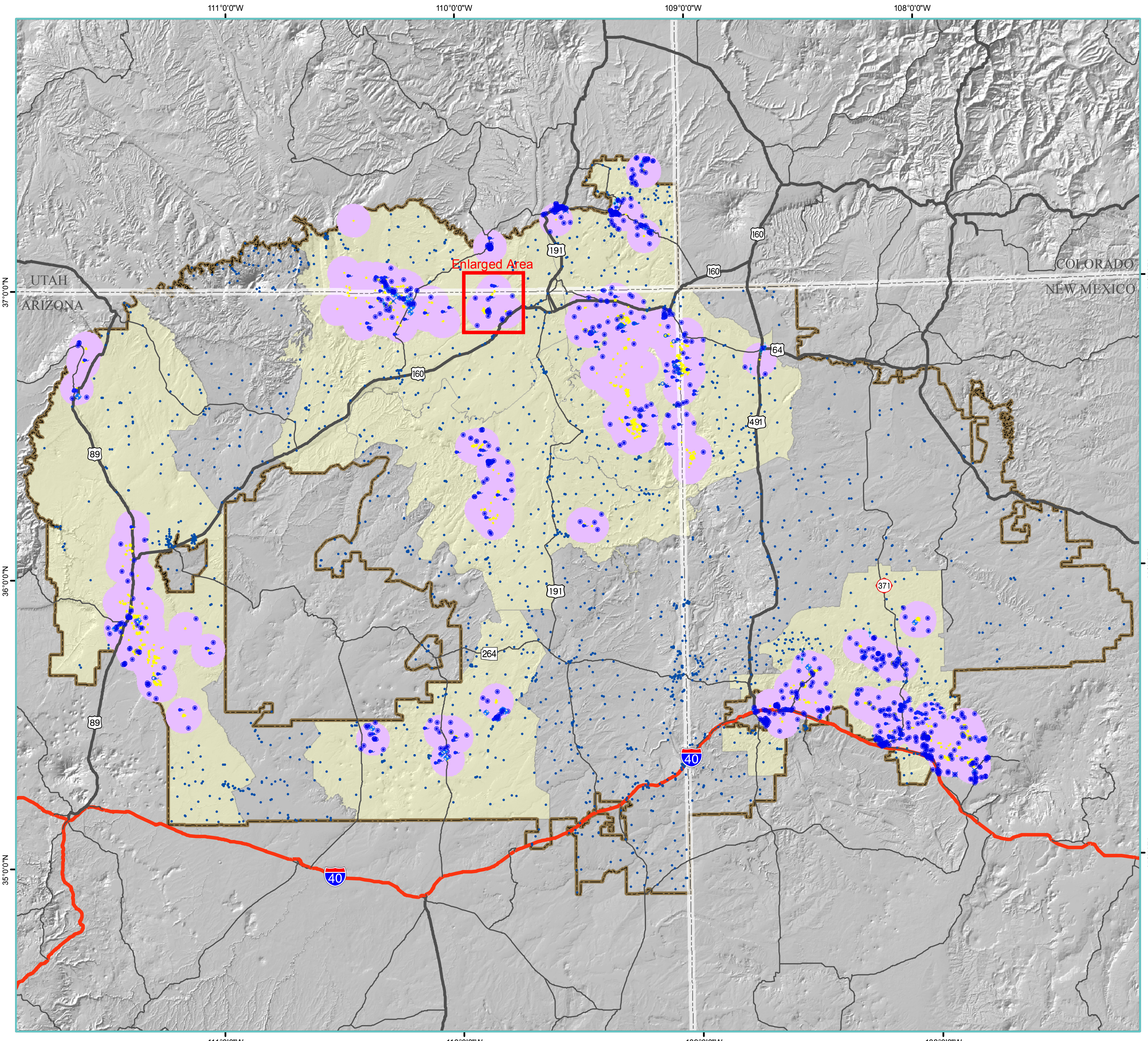
D Aquifer Direction of Ground Water Movement

RECHARGE

Rocks Receiving Recharge

Rocks Receiving Little or No Recharge

Figure 26. Water Level Contours, Direction of Water Movement, and Areas of Recharge of Aquifers On the Navajo Nation.

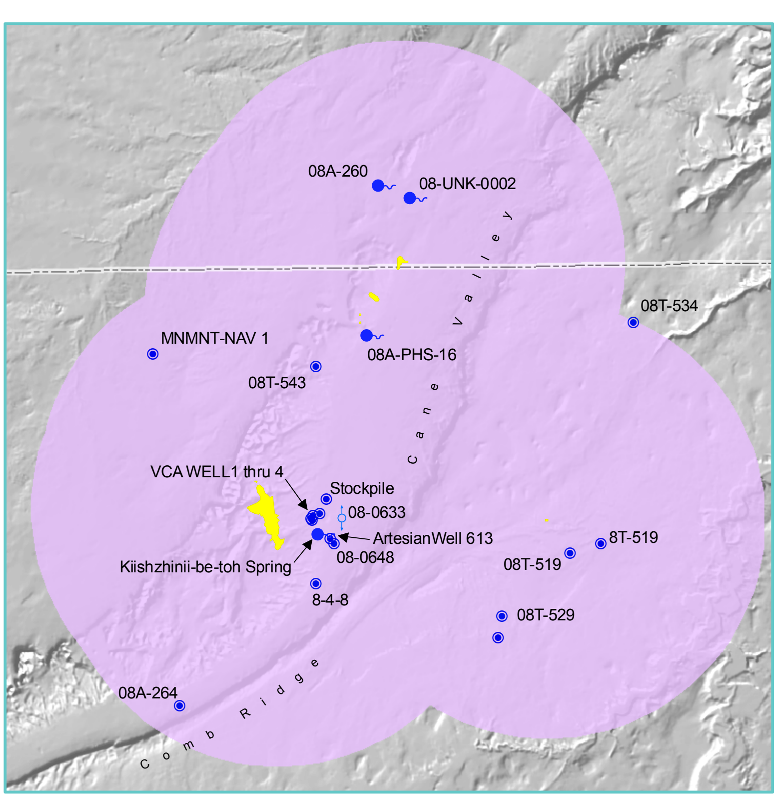


ABANDONED URANIUM MINES AND THE NAVAJO NATION

WATER SOURCES WITHIN FOUR MILES OF AN ABANDONED URANIUM MINE AND ACROSS THE NAVAJO NATION

0 50 Miles

Map Scale 1:1,750,000



Enlarged view of water sources within four miles of AUMs symbolized by "well type" in the Cane Valley, Arizona and Utah area.

Legend

TYPE OF WELL WITHIN 4 MILES OF AUM

- Artesian Well
- Developed Spring
- Natural Spring
- Unknown
- Water Well
- Well

WELLS OUTSIDE THE 4 MILE BUFFER

- All Wells

- Abandoned Uranium Mine (AUM)
- 4 Mile Buffer Around AUM

Sources

Water sources are primarily from the Navajo Department of Water Resources and augmented using data from the Arizona Department of Water Resources, New Mexico Office of the State Engineer, Utah Division of Water Rights, U.S. Army Corps of Engineers water sample locations, USGS/EPA National Hydrography Dataset, USGS Geographic Names Information System, USGS Ground Water Site Investigations Database, USGS topographic quadrangles, and USGS digital orthophotography.

Filenames: DB/Water/ NN_Wells_4mi.shp and DB/Water/NN_Wells.shp

Figure 27. Water Sources Within Four Miles of an AUM and Across the Navajo Nation.

AQUIFER SENSITIVITY

Blanchard (2002 - S01200301) cites the definition of aquifer sensitivity as “the relative ease with which a contaminant applied on or near a land surface can migrate to the aquifer of interest. Aquifer sensitivity is a function of the intrinsic characteristics of the geological materials, and the overlying unsaturated zone.” Blanchard developed a model of aquifer sensitivity for the Navajo Nation using broad physical characteristics to describe aquifer sensitivity to surface and near surface contaminants.

The factors used in the Blanchard model include geology, precipitation, soil properties, slope of the land surface, and stream courses. Each of these factors is shown to the left in Figure 28. Blanchard stated that the largest limitation to this method was inadequate information on depth to the uppermost aquifer. The following describes the inputs used in Blanchard’s (2002) assessment.

The geology was developed from Cooley et al. (1969 - S10290201). It identifies where consolidated rocks are recharged and unconsolidated deposits are at the surface and facilitate aquifer contamination (pink on the geology map in Figure 28). Geology acts as a surrogate for impact of the vadose or unsaturated zone. Yellow identifies areas that do not contribute to recharge. The eastern portion of the Eastern AUM Region was not included in the Cooley map; in order to not underestimate the contamination potential of this part of the study area, Blanchard assigned it to the “significant potential” category.

Water provides the solvent in which contaminants are transported from the land surface to the aquifers. Precipitation is the surrogate for recharge where greater precipitation results in greater potential for contaminants to infiltrate the land surface. In the precipitation map in Figure 28, pink indicates high precipitation, green indicates relatively uniform intermediate precipitation, and blue indicates the least precipitation and potential to facilitate aquifer contamination.

Several soil properties contribute to the potential to facilitate aquifer contamination, including: texture, infiltration rate, drainage, and organic content. These properties were developed from a modified version of the STATSGO, or State Soil Geographic database created by the U.S. Department of Agriculture, National Resources Conservation Service (Schwarz and Alexander, 1995 - S08030303). Blanchard further explains that finely textured soil reduces the rate at which water and contaminants move through the soil (low hydraulic conductivity). High infiltration rates indicate a soil that permits a high volume of water to enter from the land surface. Lower drainage rates indicate a higher resident time. Soil organic content affects microbial activity and sorption. Blanchard found that soils on the Navajo Nation had an organic content of less than 2 percent, indicating minimal microbial activity and sorption. With no relative difference across the Navajo Nation, organic content was not used. In the soil properties map (shown in Figure 28) blue indicates areas with the least potential, where the soil is fine-grained, has a low infiltration rate, is poorly drained, and has a high organic content. Green indicates areas with intermediate potential, and pink indicates areas with the most potential.

Land surface slope affects the ability of precipitation to infiltrate soil. Slopes less than 6 degrees (pink in the slope map in Figure 28) permit precipitation to stay in contact longer with the soil, thereby increasing infiltration of water into the land surface. Conversely, slopes of 6 to 12 degrees (intermediate slopes shown in green) and steep slopes greater than 12 degrees (blue in the slope map at left) minimize infiltration because water runs off quickly.

Blanchard developed buffered fourth-order and higher stream courses from USGS DEM’s (shown in Figure 28). Stream courses, wherever they occurred, were assigned the greatest potential to facilitate contamination because they concentrate runoff and have flat slopes. Floodplain and terrace soils are also composed of materials that facilitate contamination.

Blanchard summed the assigned numeric scores for each of the precipitation, soil properties, and slope layers and multiplied by the geology score (1 for facilitates contamination and 0 for does not facilitate contamination). A final aquifer sensitivity map was developed from these scores and is shown on Figure 29. The highest scores represent the most potential for contamination, low scores have the least potential, and intermediate scores produce intermediate potential. The insignificant category represents areas where the geology score was zero, or were not areas of recharge to bedrock aquifers, and/or were not areas of unconsolidated deposits (stream alluvial deposits).

This dataset is provided on the GIS Data DVD (DB/Water/NN_Aquifer_Sensitiviy.shp).

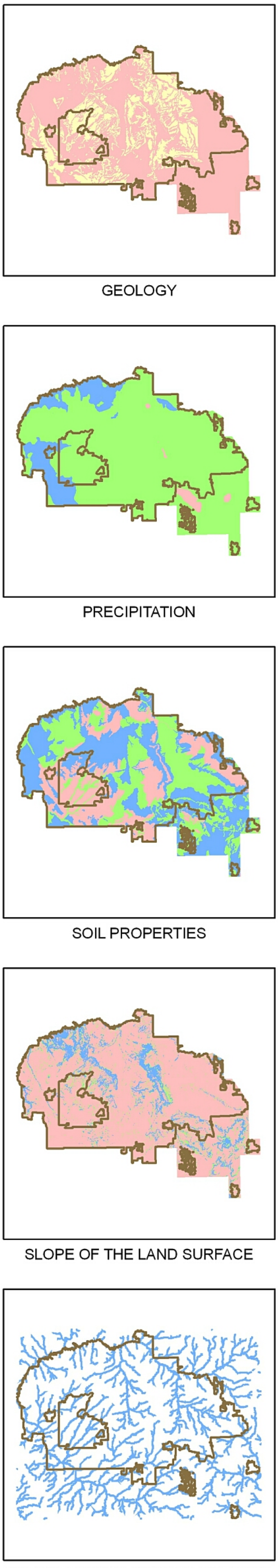
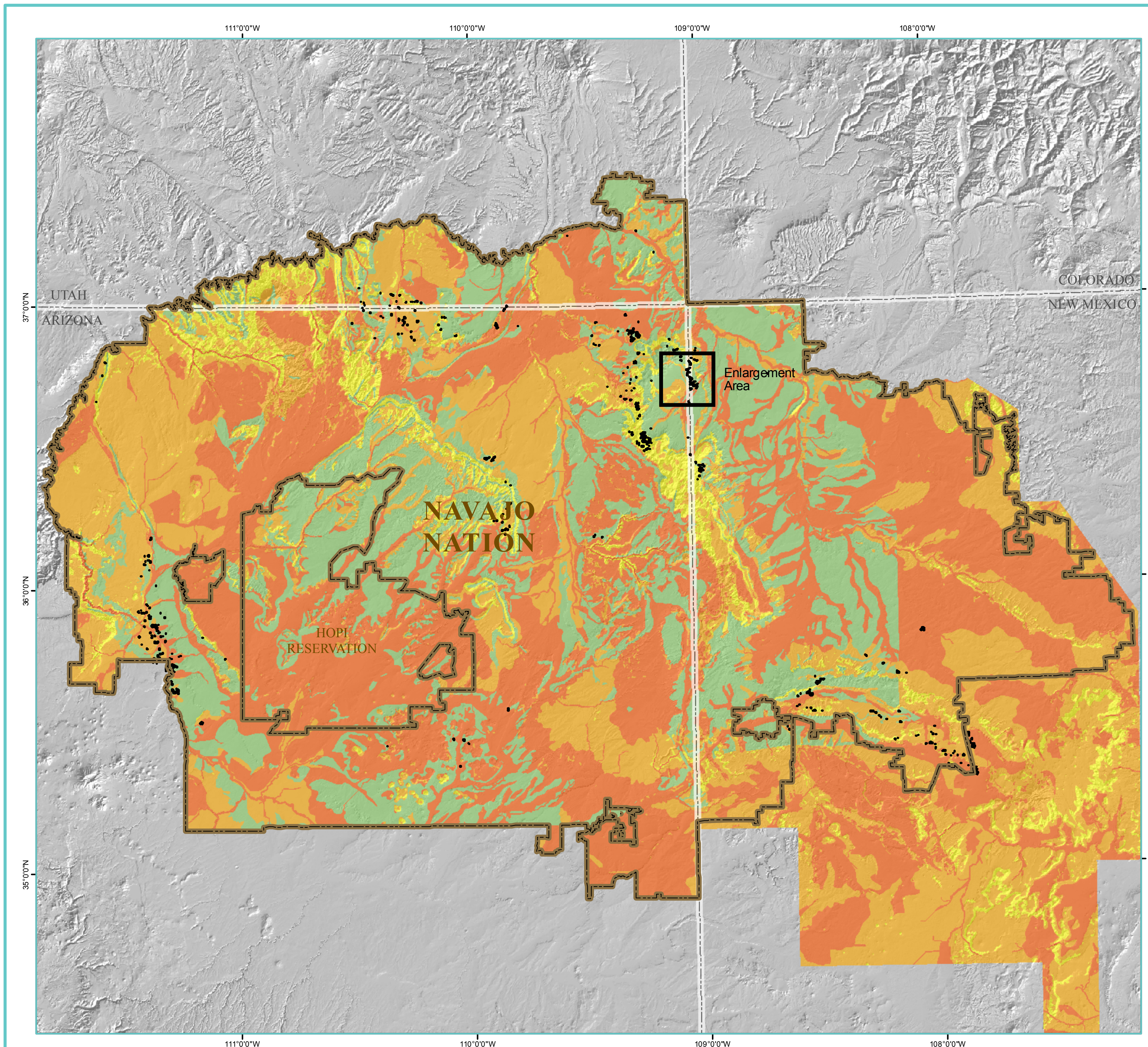
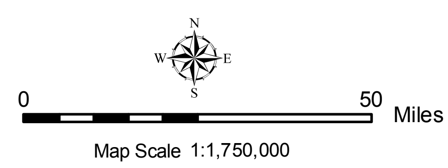


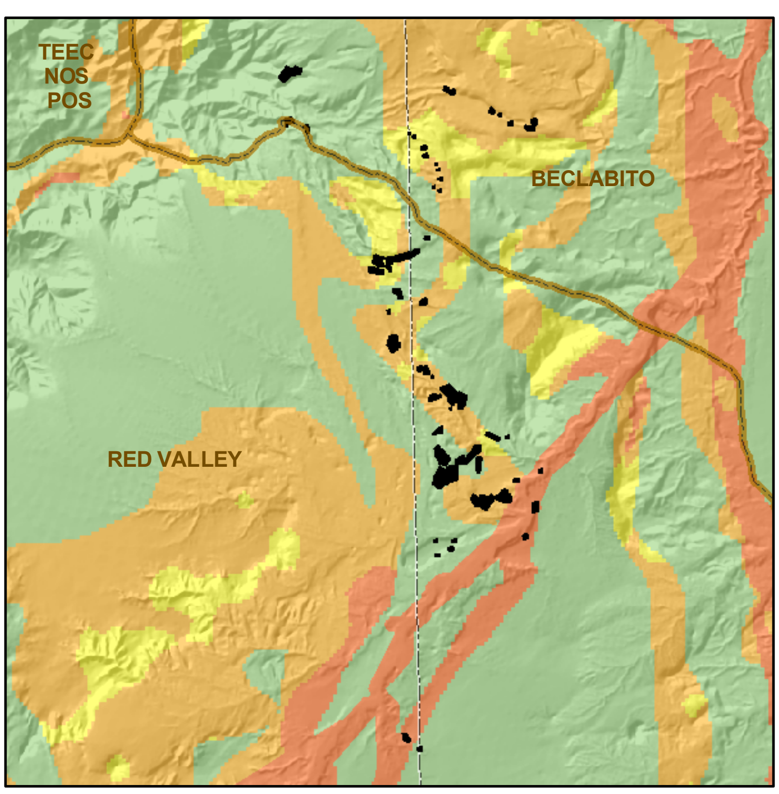
Figure 28. Inputs to Aquifer Sensitivity



ABANDONED URANIUM MINES AND THE NAVAJO NATION

AQUIFER SENSITIVITY





Enlarged view of AUMs and aquifer sensitivity in the northeast portion of the Red Valley Chapter area.

Legend

Abandoned Uranium Mines

Aquifer Sensitivity Class

- 0 - Insignificant Potential
- 1 - Least Potential
- 2 - Intermediate Potential
- 3 - Most Potential

Sources

Aquifer sensitivity was developed and provided by Paul Blanchard (2002), U. S. Geological Survey, Water Resources Division in Albuquerque, New Mexico. The data are from the Water-Resources Investigations Report 02-4051 titled "Assessments of Aquifer Sensitivity on Navajo Nation and Adjacent Lands and Ground-Water Vulnerability to Pesticide Contamination on the Navajo Indian Irrigation Project, Arizona, New Mexico, and Utah."

Aquifer sensitivity, which is shown above on a shaded relief image, refers to the potential to contaminate the ground water - ranging from "insignficant" to the "most" potential. This was determined by an investigation of the geology, precipitation, soils, slope, and stream courses of the area.

Filename: DB/Water/NN_Aquifer_Sensitivity.shp

Figure 29. Aquifer Sensitivity on the Navajo Nation.